AD-753 646

OH-6A PHASE II QUIET HELICOPTER PROGRAM

William H. Barlow, et al

Hughes Tool Company

Prepared for:

Army Air Mobility Research and Development Laboratory
Advanced Research Projects Agency

September 1972

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

AD

USAAMRDL TECHNICAL REPORT 72-29

OH-6A PHASE II QUIET HELICOPTER PROGRAM

By

W. H. Barlow

W. C. McCluskey

H. W. Ferris

September 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-69-C-0078
HUGHES TOOL COMPANY - AIRCRAFT DIVISION
CULVER CITY, CALIFORNIA

SPONSORED BY:
ADVANCED RESEARCH
PROJECTS AGENCY
ARPA ORDER 1321

U S ARMY MATERIEL COMMAND

68

DISCLAIMERS

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission, to manufacture, use, or sell any patented invention that may in any way be related thereto.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware or software.

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed. Do not return it to the originator.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Hughes Tool Company - Aircraft Division Centinela Ave. at Teale St. Culver City, California	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP -
3. REPORT TITLE OH-6A PHASE II QUIET HELICOPTER PROGRAM	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report	
5. AUTHOR(S) (First name, middle initial, last name) William H. Barlow, William C. McCluskey, Harold W. Ferris	
6. REPORT DATE September 1972	7a. TOTAL NO. OF PAGES 66 — 7b. NO. OF REFS 10
8a. CONTRACT OR GRANT NO. DAAJ02-69-C-0078 b. PROJECT NO. ARPA Order 1321 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAMRDL Technical Report 72-29 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) Hughes Report HTC-AD 71-102
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia

13. ABSTRACT

This report presents the results of the Phase II Quiet Helicopter Program. A Hughes OH-6A Light Observation Helicopter (LOH) was extensively modified to obtain a maximum of quieting. The purpose was to apply the latest known sound-suppression techniques available to industry to an actual helicopter and then to measure the results. An acoustic goal was set which required a balanced treatment of each noise-producing source throughout the full frequency range. Noise reductions ranged from 14 to 20 db depending on the flight conditions.

The report describes the detailed configuration changes, the test and development programs, and the final sound level measurements compared to the standard OH-6A.

The concept involved the adding of main and tail rotor thrust capacity to permit operation at reduced RPM and propulsion system quieting to match the overall sound level goals. The additional rotor capacity at full RPM permitted a large net gain in payload and forward speed. Two flight modes were developed: a very quiet low-RPM mode and a quiet high-performance mode. The pilot changes modes, in a few seconds, by trimming RPM in flight.

Details of illustrations in this document may be better studied on microfiche

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Quiet Light Observation Helicopter						
Noise Reduction						
Noise Measurement						
Noise Analysis						
Aural Detection						
Engine Silencer						
Rotor Noise						
Rotational Noise						
Engine Noise						
Drive-System Noise						
Acoustical Instrumentation						
Perceived Noise Level						
Noisiness						

Ib

DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by Hughes Tool Company, Aircraft Division, under Contract DAAJ02-69-C-0078.

The program was the second of two programs conducted as part of the Quiet Helicopter Program sponsored by the Advanced Research Projects Agency (ARPA). This second program involved a more extensive effort to reduce the external noise signature of the OH-6A helicopter. Efforts to reduce the noise signatures of the Sikorsky SH-3A and the Kaman HH-43B helicopters were also part of the ARPA Quiet Helicopter Program.

The external noise signature of the OH-6A helicopter was reduced a maximum of 14 to 16 decibels in level flight and 17 to 20 decibels in hover. Aural detection distances were reduced by a factor of more than 6 to 1. These results were obtained at 67% rotor rpm and 1600 pounds gross weight. At 78% rotor rpm and 2400 pounds, the noise signature was reduced 14 decibels in a hover.

This report has been reviewed by this Directorate and is technically correct.

This program was conducted under the technical management of Mr. R. C. Dumond of the Applied Aeronautics Division.

IC

Contract DAAJ02-69-C-0078
USAAMRDL Technical Report 72-29
September 1972

OH-6A PHASE II QUIET HELICOPTER PROGRAM

Final Report

Report HTC-AD 71-102

Sponsored by Advanced Research Projects Agency
ARPA Order 1321

By

W. H. Barlow
W. C. McCluskey
H. W. Ferris

Prepared by

Hughes Tool Company - Aircraft Division
Culver City, California

for

EUSTIS DIRECTORATE
U.S. ARMY AIR MOBILITY
RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

Approved for public release; distribution unlimited.

Id

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory under Contract DAAJ02-69-C-0078.

ABSTRACT

The purpose of the Phase II Quiet Helicopter program was to further reduce the noise signature of the OH-6A helicopter over that achieved during the previous program. This was accomplished by incorporating extensive modifications and by operating the aircraft at 67 percent N_2 at a gross weight of approximately 1600 pounds. The following new and/or modified components were incorporated:

New	Modified
Five-bladed main rotor system	T63-A-5A engine
Four-bladed tail rotor assembly	Main rotor transmission
Engine exhaust muffler system	Tail rotor gearbox
Acoustic blanketing	Engine air inlet and plenum chamber
Engine compartment doors	Lower vertical stabilizer

An instrumented flight strain survey was conducted to ensure structural integrity and establish a safe, practical flight envelope for the acoustics measurement portion of the program.

A movie was produced showing comparison flights of the Quiet Helicopter and a standard OH-6A.

Upon completion of the safety-of-flight review, the helicopter was transported to Wallops Island, Virginia, where NASA-Langley conducted the Government acoustics evaluation.

Only limited noise-level measurements of the fully configured test vehicle were obtained by Hughes Tool Company - Aircraft Division; however, the data recorded by NASA[1] corroborated an overall sound pressure level (OASPL) reduction of 17 to 20 decibels in hover and 14 to 16 decibels during flyover as compared to the standard OH-6A. The aural detection range of the standard OH-6A was reduced by a factor of more than 6 in the quietest flight mode of the Quiet Helicopter.

FOREWORD

This report documents the results of the Phase II program to reduce the noise signature of the OH-6A helicopter. The work was performed by Hughes Tool Company - Aircraft Division from April 1970 to April 1971 under U.S. Army Aviation Materiel Laboratories* Contract DAAJ02-69-C-0078. The program was sponsored by the Advanced Research Projects Agency under ARPA Order 1321. Technical program direction was provided by Mr. R. C. Dumond of the Eustis Directorate, USAAMRDL.

Principal Hughes Tool Company personnel associated with the program were Messrs. W. H. Barlow, R. Wagner, N. B. Hirsh, K. B. Amer, V. C. Plane, R. S. Taylor, and W. C. McCluskey. The Project Engineer was H. W. Ferris.

Mr. L. S. Wirt of the Lockheed Rye Canyon Acoustics Laboratory served as a consultant for the program.

*Redesignated Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL)

Preceding page blank

TABLE OF CONTENTS

Preceding page blank

LIST OF ILLUSTRATIONS

Figure		Page

LIST OF TABLES

INTRODUCTION

The high noise level of the present-day helicopter reduces its tactical effectiveness. The element of surprise made possible by the mobility of helicopter-supported operations is negated to a large extent by early[1] aural detection. The possibility of a helicopter-quieting program was the subject of a May 1968 meeting at the Institute for Defense Analyses in Washington, D. C. As a result of this meeting, a research and development program was initiated by the Advanced Research Projects Agency under the direction of Dr. C. J. Wang and technically administered by Mr. R. C. Dumond, Eustis Directorate, USAAMRDL.

In 1969, three helicopters -- the Sikorsky SH-3A, Kaman HH-43B, and Hughes OH-6A -- were modified for low-noise operation. The NASA-Langley Acoustics Branch conducted acoustics measurements of the noise characteristics of the three helicopters. The OH-6A achieved the greatest overall noise reduction of the three helicopters tested.

The approach for the Phase I program[2] was to concentrate on quieting the major noise producer in the OH-6A helicopter -- the tail rotor. By incorporating a four-bladed tail rotor (in lieu of a two-) and a low-speed tail rotor gearbox, the aircraft was safely operated at 70 percent N_2 with minimum gross weight (1450 pounds nominal), thus attaining overall sound pressure level reduction of 11 decibels in hover and 11.5 decibels in forward flight. This achievement represents a sound pressure decrease of approximately 73 percent.

In April 1970, a contract was awarded for a Phase II program to obtain a maximum reduction of the sound pressure level (SPL) of all noise sources on the OH-6A helicopter. Descriptions of the modifications, the test programs, and the results obtained are included in this report.

DESCRIPTION OF AIRCRAFT MODIFICATIONS AND DISCUSSION OF THE TEST PROGRAMS

DESIGN CHANGES

General

An overall noise level reduction requires commensurate reduction of all prominent noise sources of the helicopter. Reduction of one noise source, when there are other noise sources of about the same magnitude, will not produce any significant change in the overall noise level. Therefore, a comprehensive program simultaneously attacking all major noise sources was initiated. From the results of the Phase I program, the prominent noise sources for the OH-6A helicopter were identified and are shown in Figure 1. The first harmonic main and tail rotor rotational noises occur at 22 and 54 Hz, respectively. Main rotor transmission gearing noise occurs at 1000 Hz, and engine gearing noise is predominant in the 2000- to 5000-Hz range. Although not visible on the spectral plot of Figure 1 (because of masking by more prominent noise sources), broadband main-rotor vortex noise is present in the 300- to 1000-Hz range.

Main Rotor System

The design objective for the main rotor was to develop a lightweight, quiet system capable of satisfying the lift and structural load requirements when operating at reduced-rpm cruise flight with gross weight between 1600 and 2400 pounds.

Design and analysis studies were conducted on two main rotor systems -- a six-bladed rotor and a five-bladed rotor. Study results showed that the OASPL of the five-bladed system would be slightly higher than that of the six-bladed rotor, with range and performance being nearly the same. The five-bladed rotor could be operated at 67 percent N_2 at 1600-pound gross weight and at 78 or 100 percent N_2 at the maximum OH-6A gross weight of 2400 pounds. Since the six-bladed rotor would be heavier and less cost-effective, the five-bladed system was selected for the program.

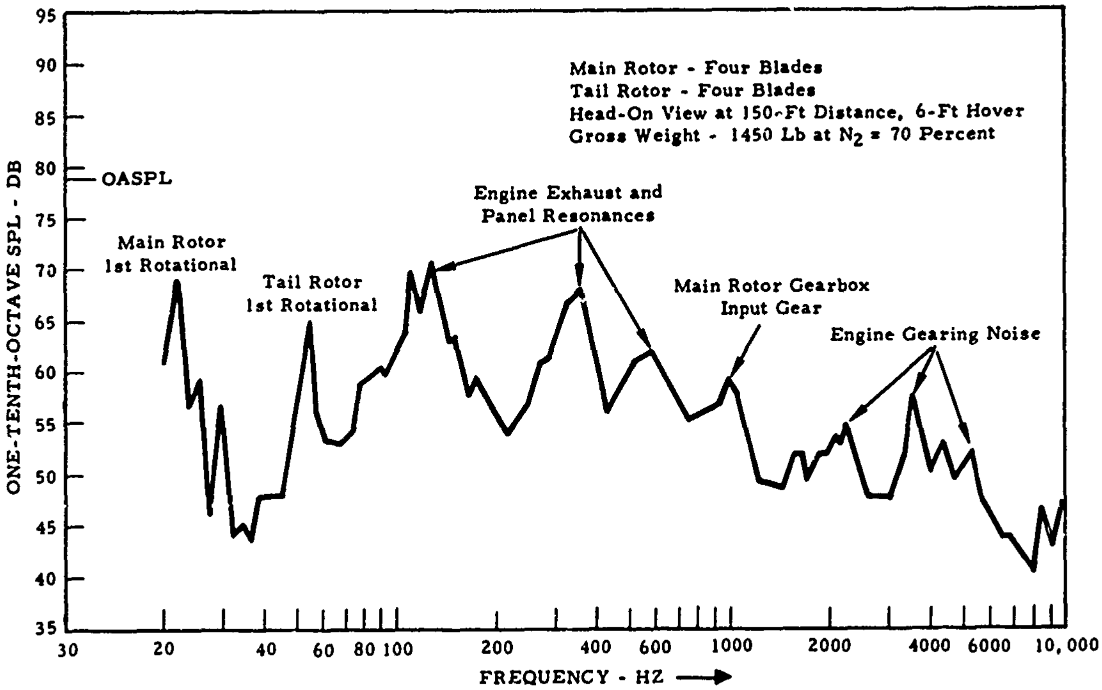


Figure 1. Noise Spectrum for Phase I Quiet Helicopter.

The new hub assembly and rotating swashplate were designed similar to those of the OH-6A, except that they accommodated a five-bladed system. To reduce the broadband vortex noise, thinned blade tips were designed, based on the results of work accomplished by Sikorsky Aircraft[3] and Bell Helicopter Company[4]. Three configurations were selected for evaluation: (1) trapezoidal with 2-degree twist, (2) trapezoidal with 4-degree twist, and (3) swept with 2-degree twist (see Figure 2). OH-6A main rotor blades were modified to accommodate the special tips.

Original plans called for selecting the optimum tip configuration by making vortex noise measurements of each of the three types while operating on the production blade tracking tower. This was unsuccessful, because the noise generated by the diesel engine masked the rotor vortex noise and no other satisfactory test stand was immediately available. Schedule constraints precluded selecting the optimum tip configuration while operating on the Quiet Helicopter.

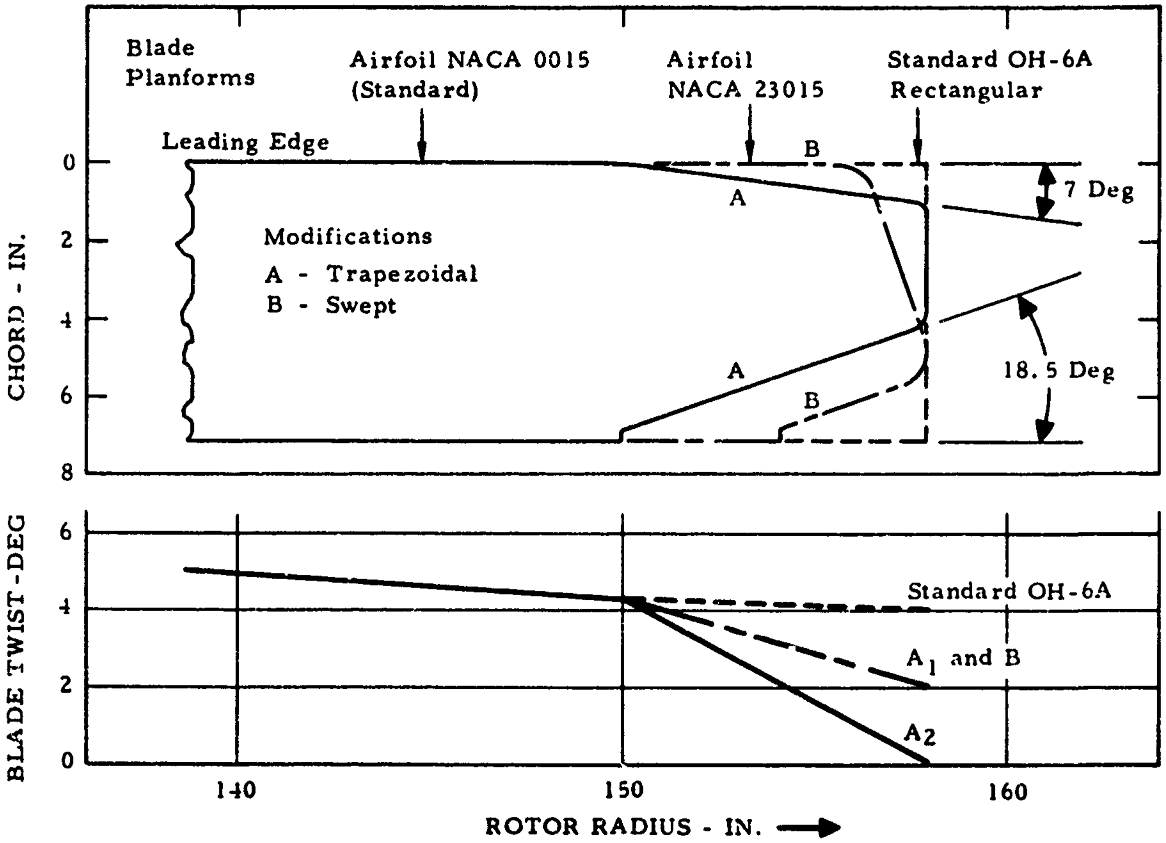


Figure 2. Quiet Helicopter Program Rotor Tip Modifications.

Therefore, the trapezoidal tips with 2-degree twist were selected by extrapolation of the Sikorsky vortex noise data.

Figure 3 is a close-up of the five-bladed main rotor system. The cylindrical component above the hub is the instrumentation slip ring for flight strain measurements.

The principal characteristics of the main rotor system are:

Number of blades: 5
Rotor diameter: 26.33 ft
Rotor disc area: 544.63 sq ft
Rotor solidity: 0.068
Airfoil section
    Basic: NACA 0015 (modified)
    Tip: NACA 23015

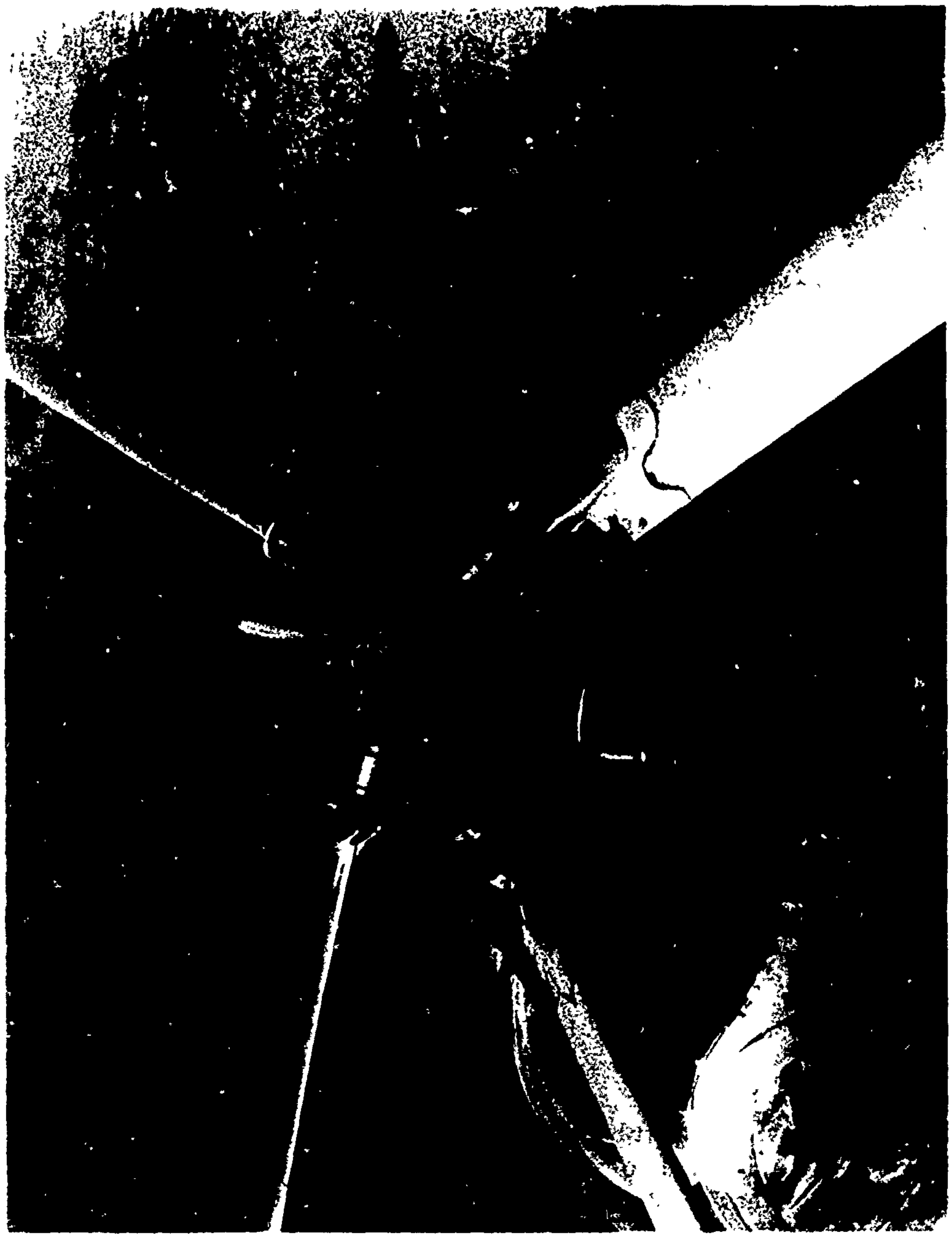


Figure 3. Five-Bladed Main Rotor System.

Blade chord: 0.562 ft
Blade area: 37.03 sq ft
Blade twist
    Basic blade: -7 deg 30 min
    Tip: -2 deg
Droop stop flapping (static): -6 deg
Droop stop coning
    Static: 0 deg
    Rotating: -2 deg
Built-in collective pitch at 3/4 radius (straps untwisted): 8 deg
Rotor speed
    At 100 percent N_2: 468 rpm
    At 67 percent N_2: 314 rpm
Rigging
    Collective pitch blade angles from neutral:
        7 to 8.5 deg (up or down)
    Cyclic pitch blade angles from neutral:

Forward	15 to 17 deg
Aft	8 to 9 deg
Left	6.5 to 9 deg
Right	5.5 to 7 deg

Tail Rotor Assembly

To meet the thrust and noise level requirements for the Phase II program, a new tail rotor was designed and tested. Two configurations were studied. The first was an eight-bladed assembly with standard blades. The second consisted of a four-bladed rotor with cambered blades and an increased diameter (from 52 to 59 inches). Based on acoustic analysis, the SPL of the eight-bladed tail rotor would be lower than that of the four-bladed assembly, but the OASPL of the helicopter would be decreased only 1 db. Thus, the increase in cost, weight, aft cg problems, and complexity of the eight-bladed assembly was not warranted. The four-bladed assembly was therefore developed.

The angular relationship (phase angle) of the four blades was then considered. Sound-level measurements recorded during the Phase I program showed that a 60-degree-by-120-degree phase-angle relationship produced rotational noise harmonics at the same frequencies as a two-bladed rotor, but with substantially reduced SPL as a result of the lower tip speed.

Studies of automotive fan data[5] indicated that, with a four-bladed fan, as the phase angle is increased from 60 to 90 degrees, the OASPL is decreased. This is graphically shown in Figure 4. However, since the 90-degree phasing produces noise at twice the frequency of 60-degree-by-120-degree phasing, the question of perceived (audible) noise was considered. Also, Coriolis forces are higher on a 90-degree-phased system. It was decided to select the tail rotor assembly after determining the phase-angle effect on OASPL and aural detectability. Three configurations were selected -- 60-degree-by-120-degree, 75-degree-by-105-degree, and 90-degree-by-90-degree.

Because of the unavailability of the fully configured Quiet Helicopter, a standard OH-6A was used to evaluate tail-rotor phase angles. The aircraft was ground-run with the main rotor in flat pitch. Tail rotor thrust and blade angle were recorded while sound level measurements were made of rotational noise. Tests were conducted on the 75-degree tail rotor at 70, 85, and 100 percent N_2 and on the 60-degree assembly at 70 and 85 percent N_2. Noise recordings were processed to obtain the noise levels of the first rotational harmonic frequency (2-per-revolution) at several points in time during each recorded run and averaged. This was necessary because of variations in tail-rotor thrust. Higher rotational harmonic frequencies were not obtainable, because they were masked by the engine exhaust noise.

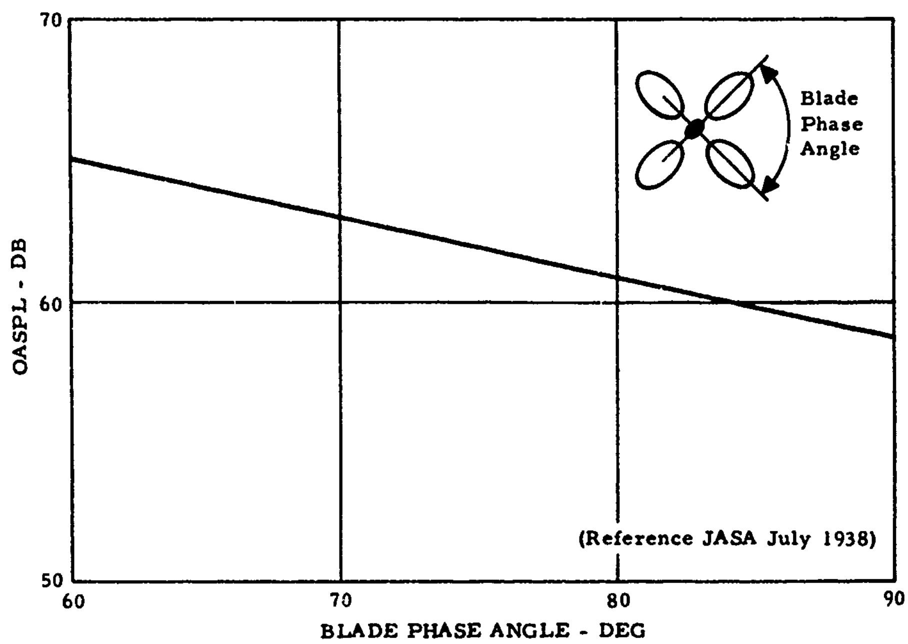


Figure 4. Blade-Phase-Angle Effects on Four-Bladed Automotive Cooling Fan.

The average noise level of the first harmonic is shown in Table I for each frequency measured. Estimated noise levels of the 90-degree assembly, together with possible load problems, ruled out this configuration as a high-risk item. The estimated noise levels of the 90-degree rotor were obtained from the noise charts of USAAVLABS Technical Report 68-60[6]. The acoustic superiority of the 75-degree rotor is indicated.

A dynamic problem occurred during the initial ground runs with the 75-degree four-bladed tail rotor installed on the aircraft when a tail rotor 2-per-rev vibration occurred at 100 percent N_2. The fluctuations in tail-rotor bending loads, as read on the cockpit indicator, were particularly noticeable at this rpm. A subsequent ground run using the 60-degree assembly showed a recurrence of this high-level tail-rotor 2-per-rev vibration at N_2 settings above 85 percent.

To determine the cause of the tail-rotor 2-per-rev vibration, additional tests were conducted using the 75-degree assembly. During ground run, rpm sweeps confirmed that the vibration was primarily lateral, which indicated a flapwise bending problem. A ground shake test was conducted to determine nonrotating chord and flap natural frequency. Results were inconclusive, because of a difference in tail-rotor hub impedance between rotating and nonrotating conditions. Ground run rpm sweeps with instrumented tail-rotor blades and hub indicated high flapwise response from 90 to 103 percent, with a chordwise resonance at 79 percent N_2. Removal of the main rotor blades and vertical stabilizers produced only minor tail rotor improvement.

TABLE I. TAIL ROTOR ROTATIONAL NOISE*

	N_2 Speed		
Phase Angle	70%	85%	100%
60°	68 db**	77 db**	-
75°	66 db**	73 db**	79.5 db**
90°	67 db***	74 db***	81 db***

*Thrust corrected.
**SPL of first harmonic; microphone 75 ft distance; 330 deg to rotor plane.
***Estimated.

These tests indicated that the flapwise bending problem might be reduced by changing the forward mass balance of the tail rotor blades at the tip area and by increasing tip contour stiffness. These changes were accomplished by adding 50 grams of weight in the leading edge at the tip and stiffening the contour of the outboard 3.5 inches of the blades by installing 4-lb/ft^3-density polyurethane-foam fillers.

The modifications to the tail rotor blades caused a 15 percent reduction of peak flapwise response. The range of rpm for this response was changed from 90-to-103 to 86-to-90 percent, with very low response in the range near 100 percent rpm. Peak chordwise response was lowered to 73 percent rpm, with an acceptable response at 70 percent rpm. Initial rpm sweeps during hover corroborated the above results; however, after wear-in, subsequent rpm sweeps in hover and 60-knot forward flight indicated a lowering of peak response frequencies to 82 percent flapwise and 68 percent chordwise. An external tip weight of 50 grams was temporarily added to lower the chordwise resonance below the desired operating range of 67 percent rpm. A ground rpm sweep confirmed that this weight was sufficient. Consequently, a permanent 45-gram aluminum tip cap was incorporated in each blade. Flight tests indicated improvement, but it was not adequate to reduce the flight loads for an acceptable flight envelope.

Further testing was accomplished to evaluate the effect of tail rotor flapwise and chordwise loads when using a combination of one pair of unmodified tail-rotor blades and a pair of modified tail-rotor blades. Results showed little improvement, so this approach was abandoned.

The effect of a reduction in the scissor mode stiffness of the tail-rotor assembly on vibratory load response was investigated. Slotting of the tail-rotor blade mounting forks provided a feasible technique by which the restraint for the scissor mode (hub chordwise moment) could be reduced without significantly affecting either flapwise or chordwise symmetrical stiffness values. The structures test laboratory experimentally determined the unmodified fork stiffness and the stiffness after slotting. A lower spring rate in the chordwise direction was established, which analysis indicated should drop the loads to an acceptable level. After eliminating all fork stiffness effects from the instrumentation, the final slotted fork configuration was proof-loaded to 7000 inch-pounds to verify the adequacy of its strength. No yielding occurred.

Cyclic loads, when using the slotted tail-rotor blade forks, were still above the endurance limits for some of the conditions tested. A flight spectrum was then established that minimized cyclic loads above the endurance limit and allowed a sufficient life to meet the anticipated requirements of the program.

The tail-rotor assembly is a four-bladed, semirigid, type employing two sets of blades mounted 2.75 inches out of plane 75/105 degrees apart on a common fork (see Figure 5). Its principal characteristics are:

Number of blades: 4
Rotor diameter: 4.84 ft
Rotor disc area: 18.40 sq ft
Blade chord: 0.40 ft
Blade twist: -7 deg 7 min
Blade area: 3.872 sq ft
Solidity: 0.204
Airfoil sections: NACA 63-415
δ_3: 30 deg
Droop stop flapping
  Soft: 10 deg
  Hard: 15 deg
Built-in collective pitch at 3/4 radius (straps untwisted): 7.5 deg
Rotor speed
  At 100 percent N_2: 1899 rpm
  At 76 percent N_2: 1272 rpm
Rigging - blade pitch angles at 3/4 radius
  Right pedal: 12 to 14 deg
  Left pedal: 28 to 29 deg

Main Rotor Transmission

A standard main rotor transmission was modified for quieter operation, as shown in Figure 6. The diametral pitch and contact ratios of the two gear sets were increased as indicated in Table II.

Dampening material was added to the first- and second-stage pinions, the first-stage gear, and the shaft that supports the output gear. Helical accessory gears replaced the standard spur type, and Turbo 35 (7-centistoke) oil was used in lieu of MIL-L-23699. A soundproof blanket made up of compressed fiberglass and leaded vinyl sheet was installed around the mounting interface of the transmission to prevent noise leakage. Table III shows the main rotor transmission gear ratio summary for the OH-6A and the Phase II Quiet Helicopter.

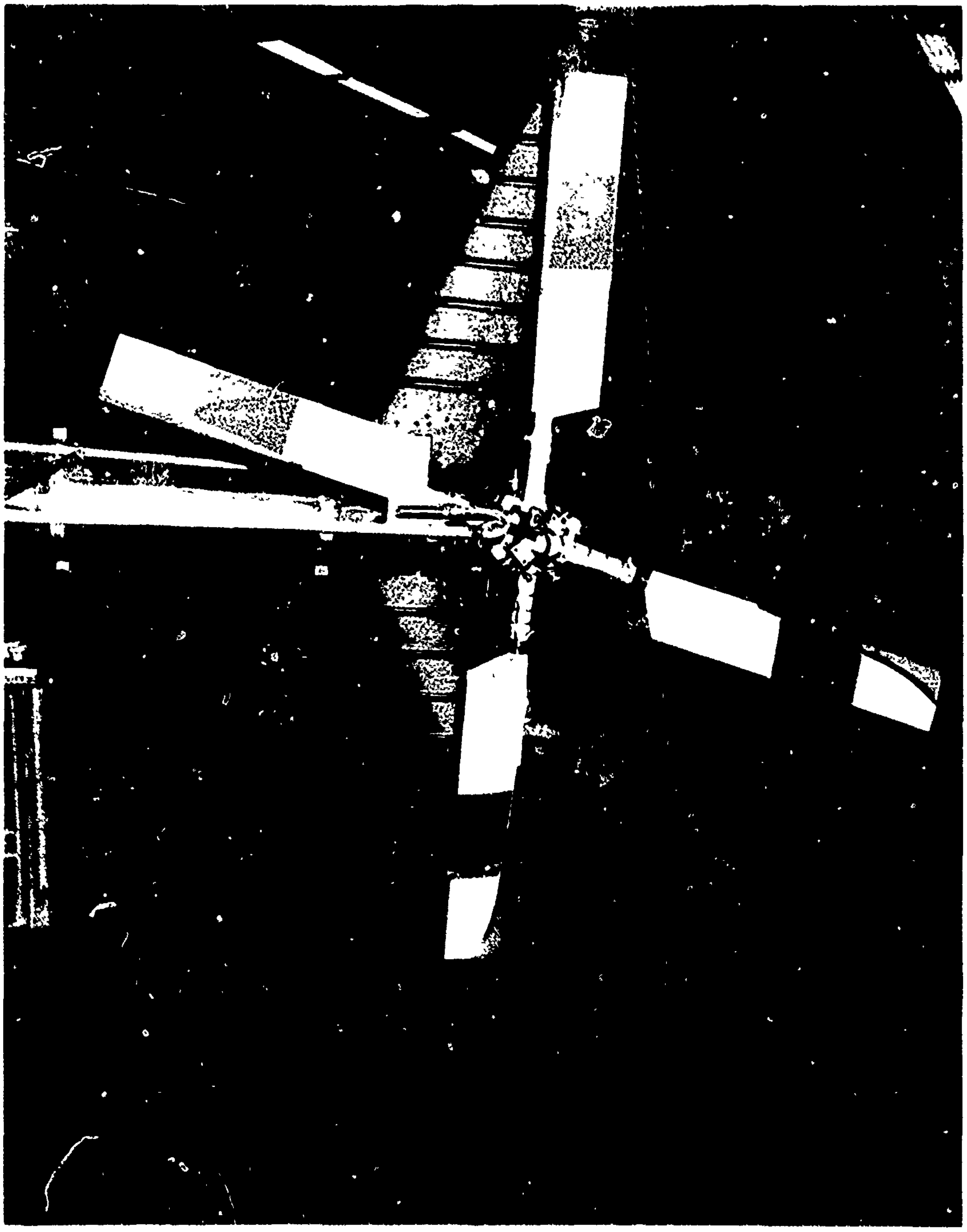
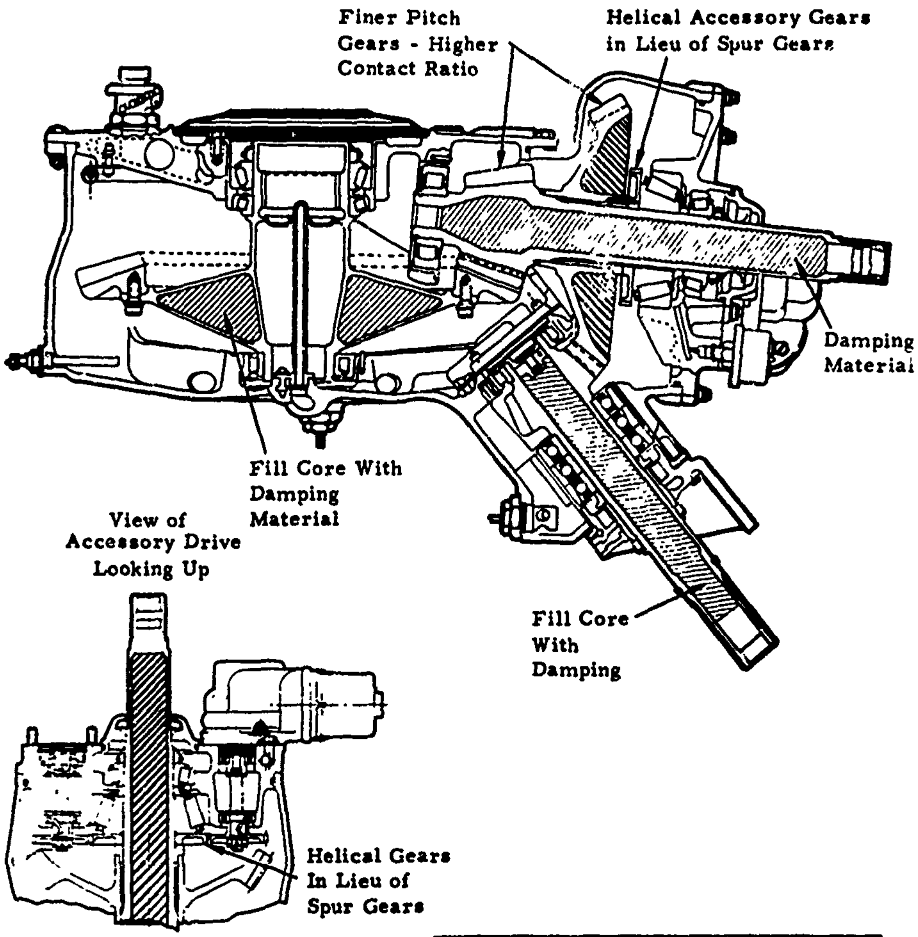


Figure 5. Four-Bladed Tail Rotor - 75-Degree-by-105-Degree (Shown With Instrumentation).



	Present Ratio 1.6-Tooth Contact	New Ratio 2.0-Tooth Contact
Input Drive Bevel Set	15 to 44	17 to 50
Output Drive Bevel Set	11 to 48	14 to 61

Figure 6. Main Transmission Assembly.

TABLE II. COMPARISON OF DIAMETRAL PITCH AND CONTACT RATIOS

Gear Set	Diametral Pitch: OH-6A	Diametral Pitch: Quiet Helicopter	Contact Ratio: OH-6A	Contact Ratio: Quiet Helicopter
High-speed	5.77	6.56	1.98	2.17
Low-speed	3.80	4.82	2.25	2.73

TABLE III. MAIN-ROTOR TRANSMISSION GEAR RATIO SUMMARY

Main Transmission	OH-6A Teeth	OH-6A RPM	Phase-II Quiet Helicopter Teeth	Phase-II Quiet Helicopter RPM
1st stage reduction				
Pinion (engine input)	15	6000	17	6000/4020*
Gear (tail rotor drive shaft)	44	2045	50	2040/1367*
2nd stage reduction				
Pinion (tail rotor drive shaft)	11	2045	14	2040/1367*
Gear (main rotor)	48	468	61	468/314*
Accessories				
Drive gear	88	2045	84	2040/1367*
Driven gear	43	4185	41	4180/2801*

RPM shown at 100 percent N_2 engine speed except as noted.

*At 67 percent N_2.

Tail Rotor Gearbox

The tail rotor transmission developed for the Phase I program was modified to further reduce the tail rotor rpm as shown in Table IV. When operating in the quiet mode, at 67 percent N_2, the tail rotor speed is 58 percent less than that of the standard tail rotor at 100 percent. The output shaft was lengthened and made stronger and stiffer to accommodate the four-bladed tail rotor system.

TABLE IV. TAIL-ROTOR TRANSMISSION GEAR RATIO SUMMARY				
	OH-6A		Phase II Quiet Helicopter	
Tail Rotor Gearbox	Teeth	RPM	Teeth	RPM
Input gear (drive shaft)	31	2045	27	2040/1367*
Output gear (tail rotor)	21	3019	29	1899/1272*

RPM shown at 100 percent N_2 engine speed except as noted.

*At 67 percent N_2

Engine Noise Suppression

Engine noise-suppression requirements were critical and could not be defined using the helicopter noise spectrum shown in Figure 1. Standard tail pipes, which distort the exhaust noise, were installed on the aircraft when the measurements were recorded, and the compartment surrounding the engine altered the casing noise. Thus, a complete spectrum of each noise source (exhaust, inlet, and casing), measured separately, was necessary to determine its respective noise-reduction requirements.

The engine noise-attenuation program was accomplished by building ground-test facilities suitable for separating the engine noise sources into components for definition of suppression requirements. Consultants expedited the work and assisted in directing the program for optimum results. To this end, Detroit Diesel, Allison Division of General Motors, was contracted to study and provide for basic engine noise reduction. Bolt, Beranek, and Newman (BB&N) and Mr. L. S. Wirt (Lockheed-California Acoustical Engineer) were contracted to assist in muffler selection and design.

The engine-noise-attenuation ground test stand is shown in Figure 7. It consists of an inlet suppressor, a BB&N-designed exhaust muffler, and an engine case suppressor, each capable of separate removal. Microphone positions were selected to allow component noise measurements on a simplified basis. Engine noise suppression obtained with the test stand was as indicated by the sound power level spectrum shown at the bottom of Figure 8.

Engine Modifications

Standard engine component noise measurements obtained are shown in Figures 8, 9, and 10 for the exhaust, inlet, and casing, respectively. The exhaust noise level from two ports is less than that of one port at high frequencies. This is possibly due to phase cancellations in the noise spectrum. The magnitude of the combined noise-reduction requirements indicated that basic engine modifications should be considered. In an attempt to reduce the amplitude or character of the noise, the aid of Detroit Diesel, Allison Division of General Motors Corporation was solicited to discuss "shotgun" approaches for reducing engine noise at the source. As a result of this meeting, Allison was contracted to incorporate the following changes in a standard T63-A-5A engine:

1. The first-stage turbine nozzle was shot-peened to reduce the effective area, thereby producing a sonic throat. This sonic barrier was created to prevent suspected air-column resonances between the exhaust system and burner volumes and possibly reduce exhaust noise.

2. All major rotating components were balanced to a much closer tolerance than in standard production engines, with the objective of reducing engine casing vibration noise and resultant aircraft vibratory noise.

3. Engine gearing was carefully matched, and lapped addendums were reduced to the minimum blueprint values. A "quiet" oil pump was installed.

4. The first- and second-stage compressor vanes, along with the third- and sixth-stage blades, were clipped in an effort to reduce inlet siren noise by increasing blade/stator spacing.

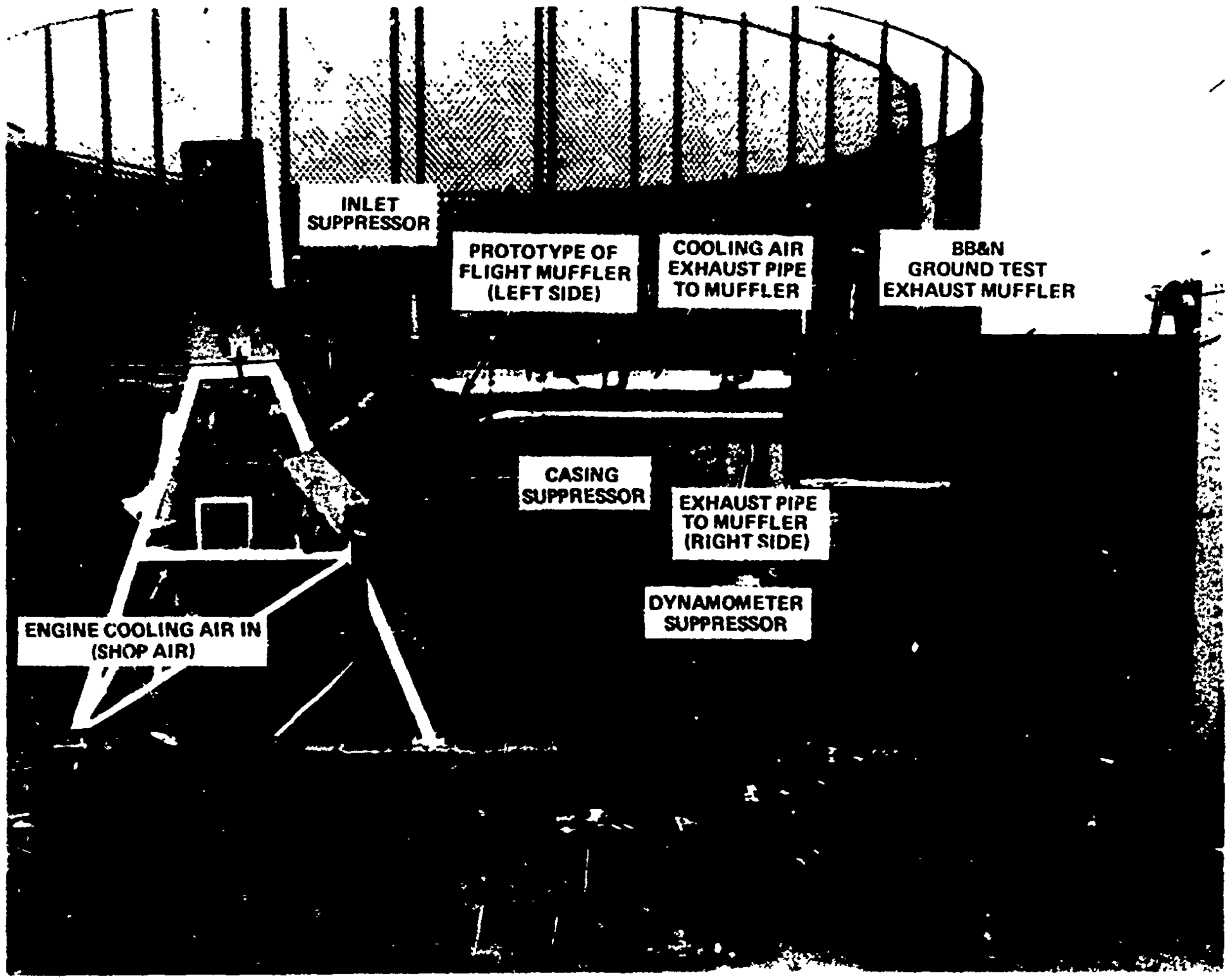


Figure 7. Engine-Noise-Attenuation Ground Test Stand.

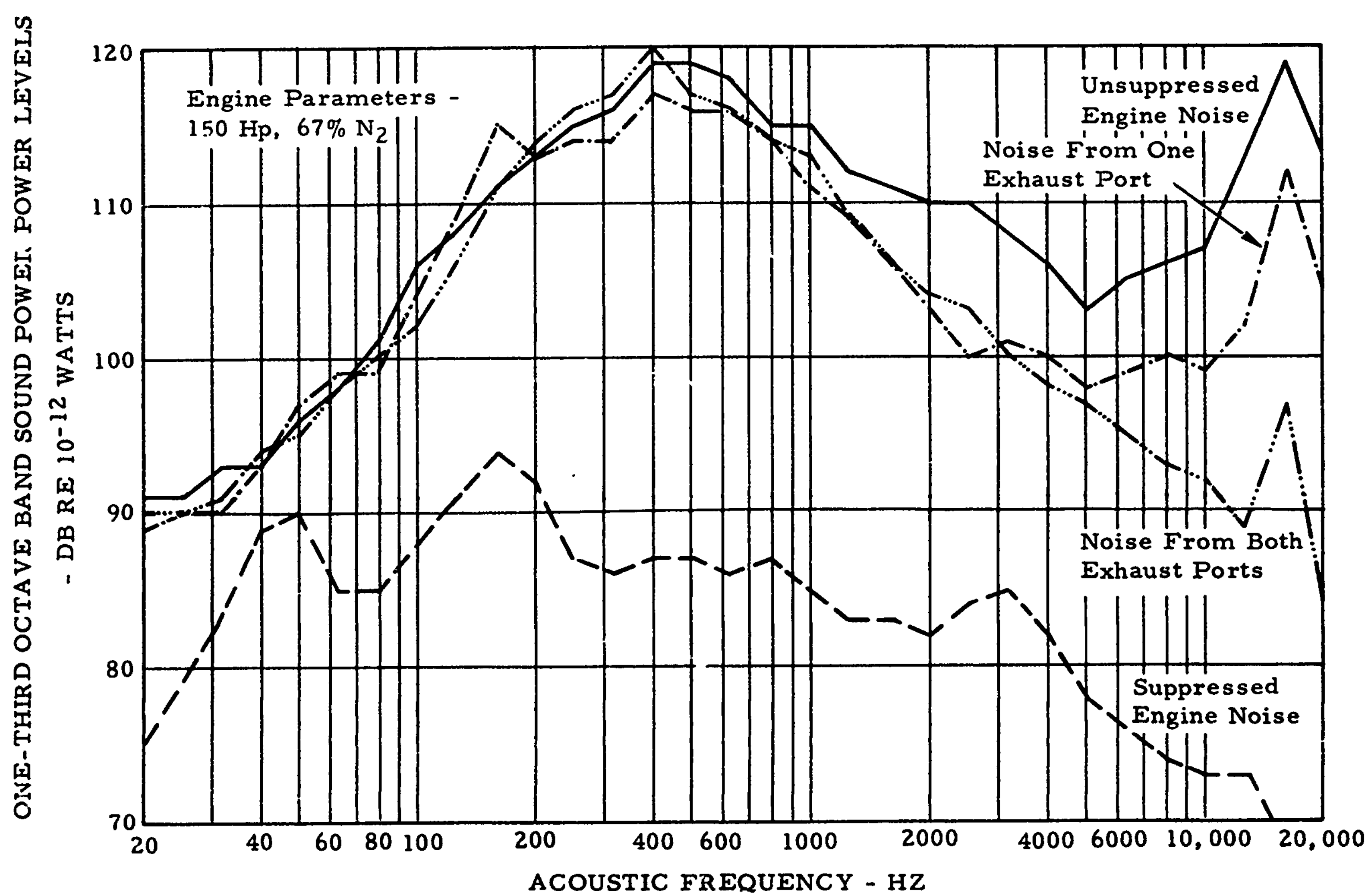


Figure 8. Standard T63-A-5A Engine Noise From One and Both Exhaust Ports.

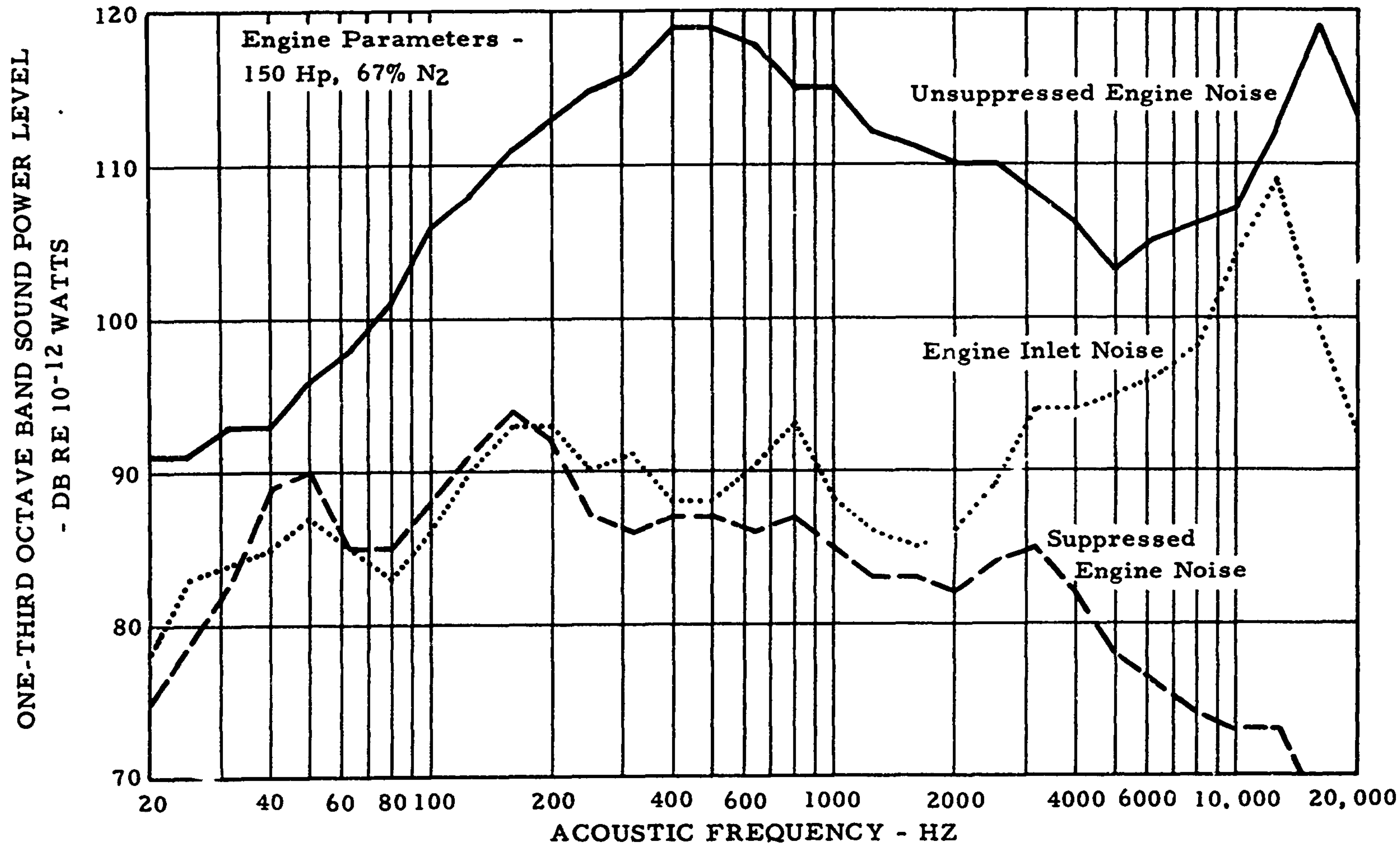


Figure 9. Standard T63-A-5A Engine Inlet Noise.

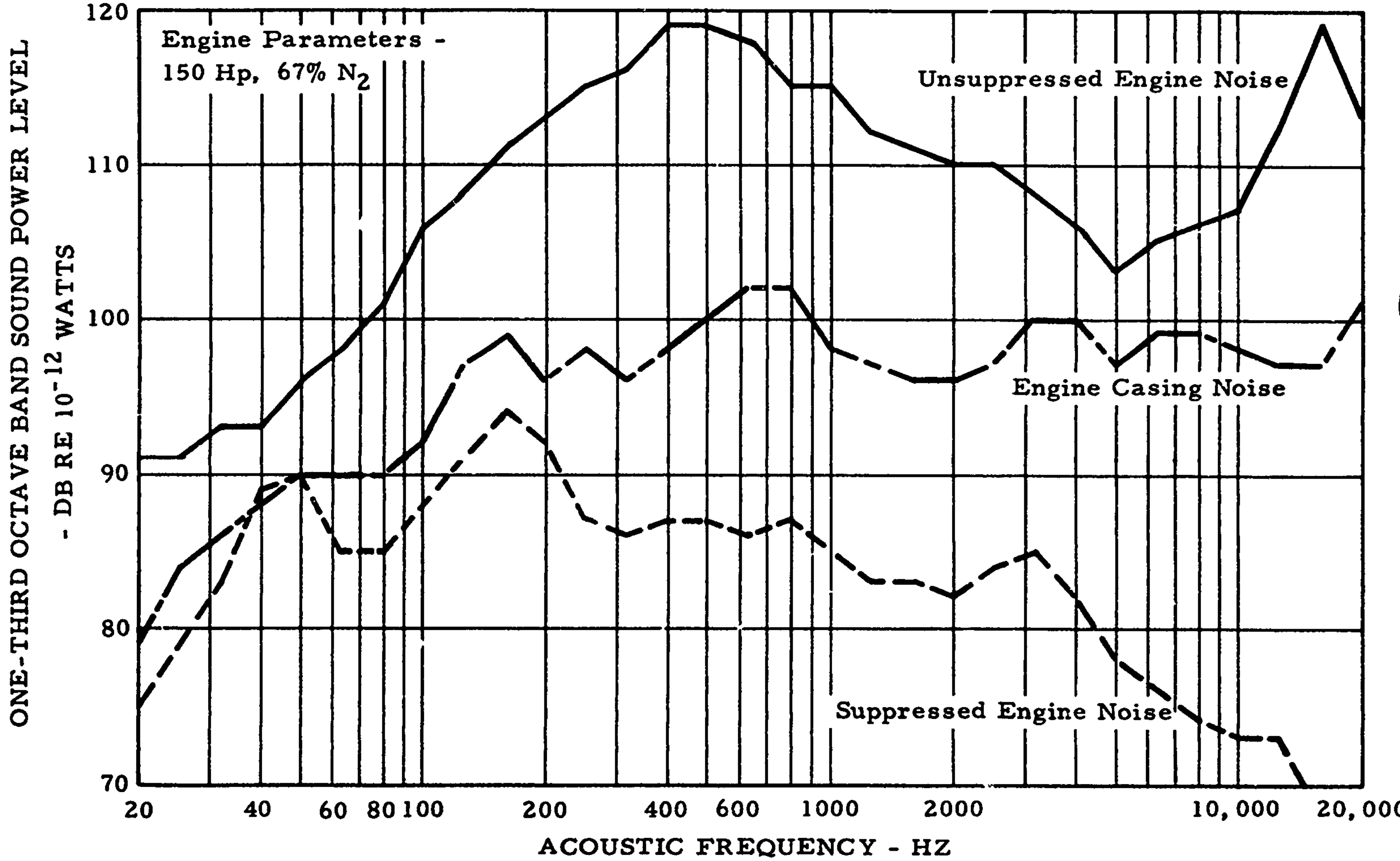


Figure 10. Standard T63-A-5A Engine Casing Noise.

5. The fifth-stage bleed valve was adjusted to be completely closed at 120 to 150 hp so that the low-horsepower compressor-noise leak to the engine compartment would be eliminated.

Results of acoustic testing with the special engine are compared with those for the standard engine in Figures 11 and 12. In Figure 11, the exhaust noise peak is decreased 2 db and engine casing noise is generally reduced. Figure 12 shows that compressor noise (15,000 Hz) is reduced slightly by the blade and vane clipping. The effects of higher power operation on the noise levels of standard and special engines are shown in Figure 13. Here again, a 2- to 3-db advantage in noise level with the special engine is obtained. The noise levels were sufficiently improved over the standard engine to warrant use of the special engine for the Phase II Quiet Helicopter program.

Muffler Development

The detailed design specification for the exhaust muffler was established as: (1) attenuation of 34 db at 500 Hz (noise spectra for single exhaust, Figure 8), (2) pressure drop at design point (150 hp, N_2 = 67 percent) of 10 to 15 inches H_2O, (3) weight not to exceed 60 pounds, and (4) fit within the existing engine compartment with heat insulation sufficient to maintain acceptable temperatures.

Bolt, Beranek, and Newman, Inc., accomplished a preliminary design analysis on a reactive-type muffler based on the work of P. M. Morse[7] and L. Cremer[8]. The concept consisted of a rectangular-duct-series system with one porous wall that reacted with matched volumes to obtain the desired attenuation (Figure 14). The final configuration was to be contour-fitted "saddle fashion" over and around the engine (Figure 15). Acoustic testing results of a laboratory model are shown in Figure 16.

During the study phase of the BB&N muffler, it became apparent that the muffler might not meet the weight and space limitation criteria. Therefore, a second design was initiated by HTC-AD with the assistance of a consultant, Mr. L. S. Wirt of the Lockheed Rye Canyon Acoustics Laboratory. This was a double-expansion, reactive-type muffler patterned after information contained in NACA Technical Report 1192[9]. A prototype of the NACA muffler concept was built and developed during a test program, using the noise-source-separated engine test stand. The final configuration was shaped to fit the aircraft, using an effective volume ratio, m of 4.5 (ratio of muffler cross section area to cross-over pipe area).

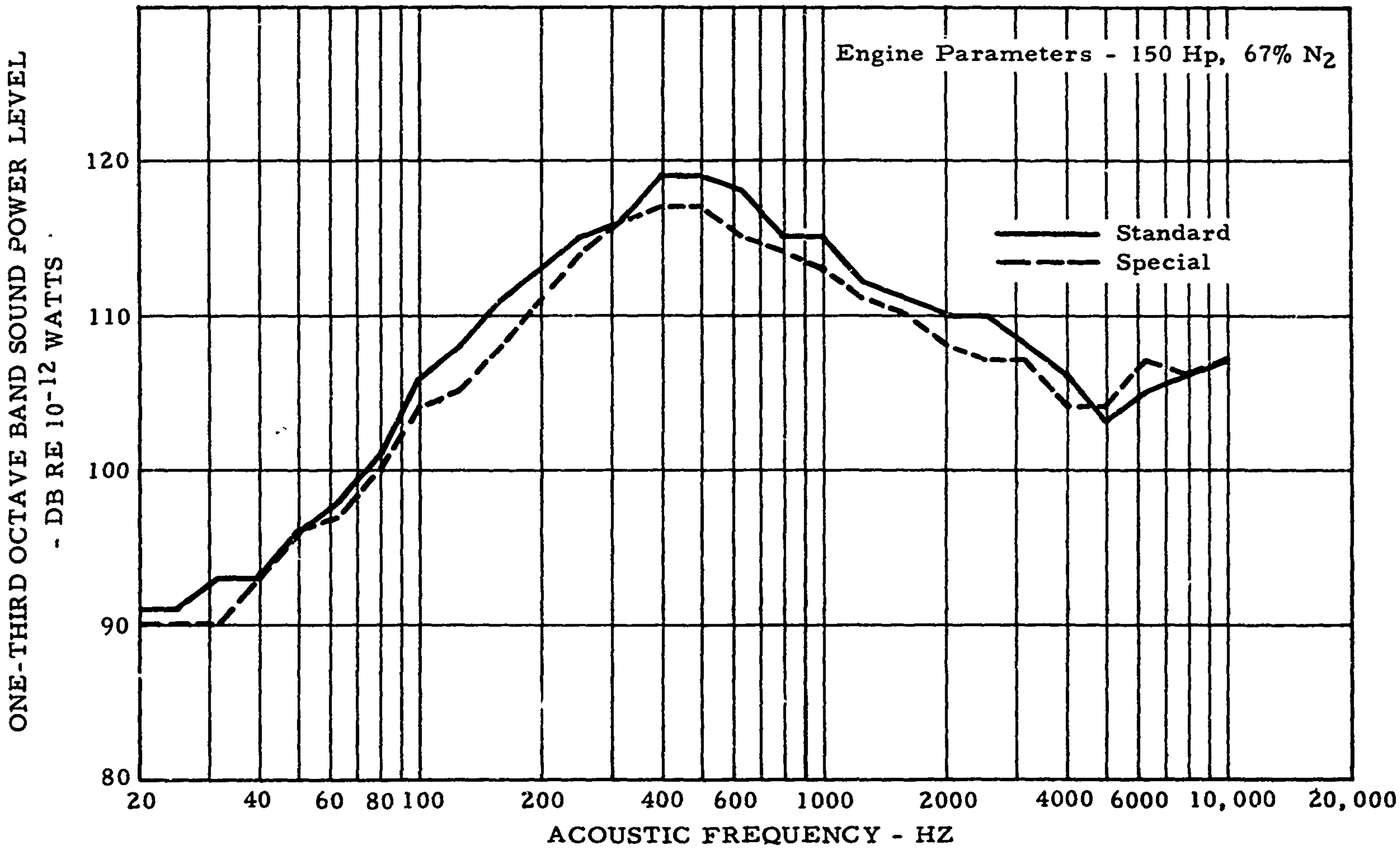


Figure 11. Standard and Special T63-A-5A Engine Unsuppressed Noise Comparison.

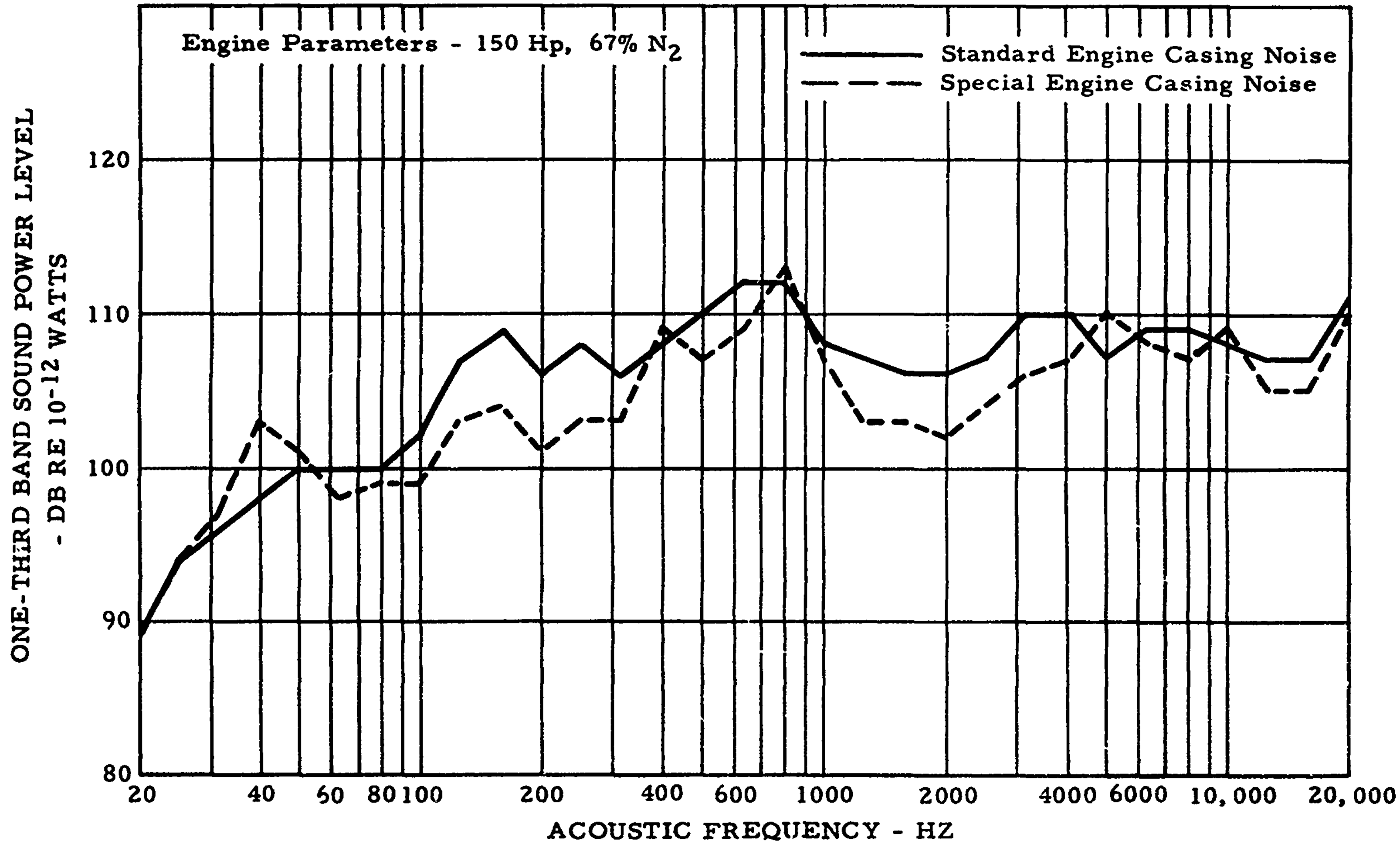


Figure 12. Standard and Special T63-A-5A Engine Casing Noise.

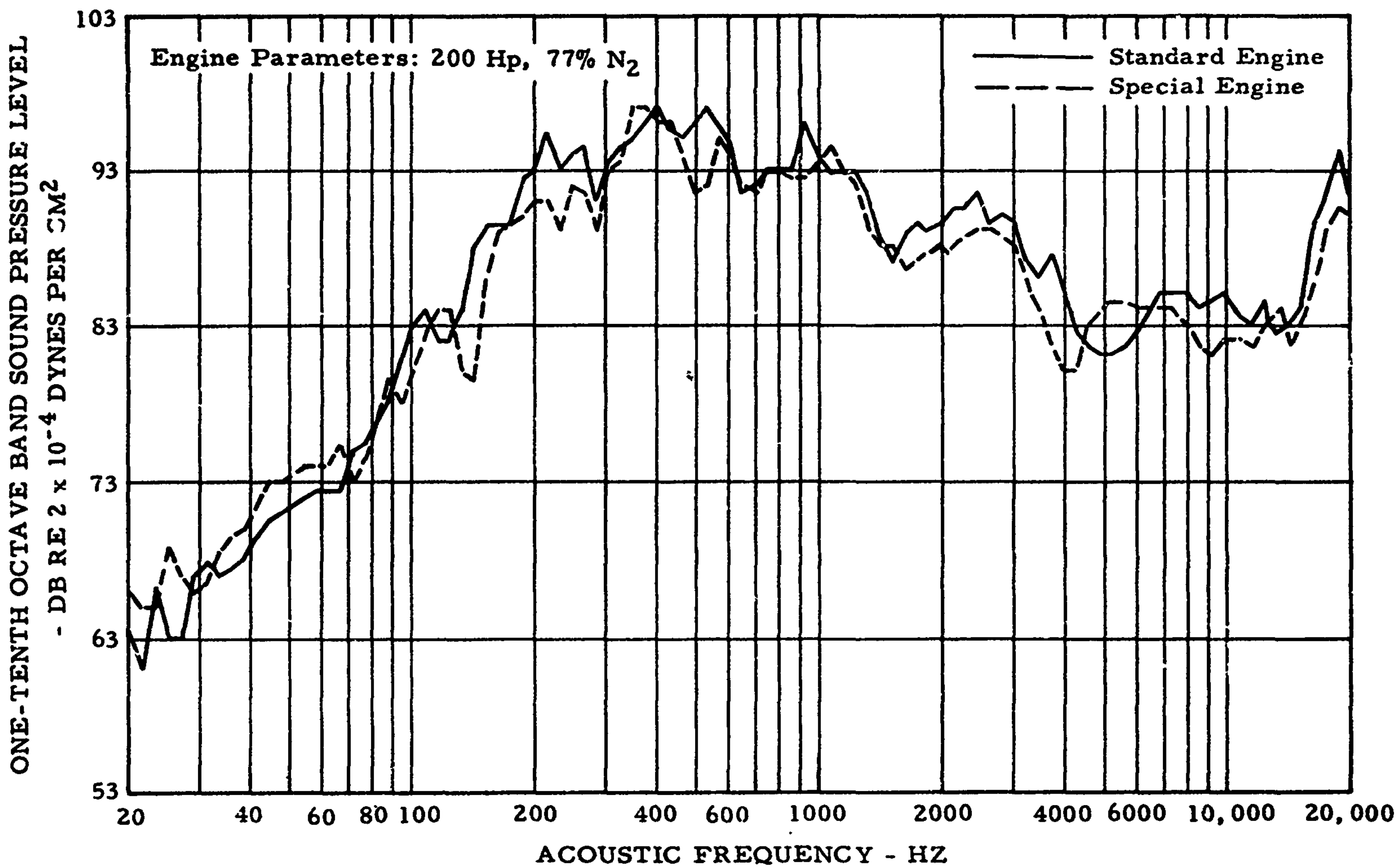


Figure 13. Unsuppressed T63-A-5A Engine Noise, Microphone Position 10 Feet to Left and 80 Degrees From Engine (Forward) Centerline.

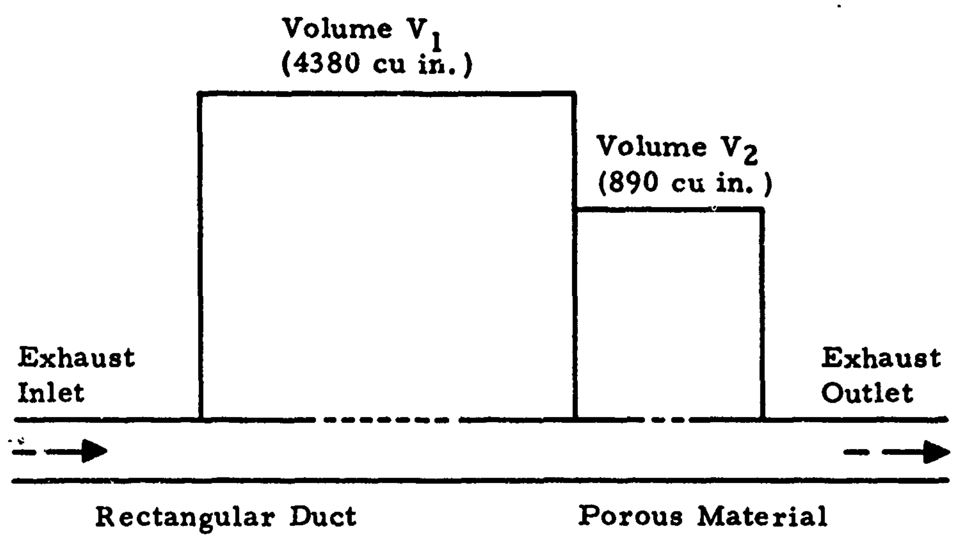
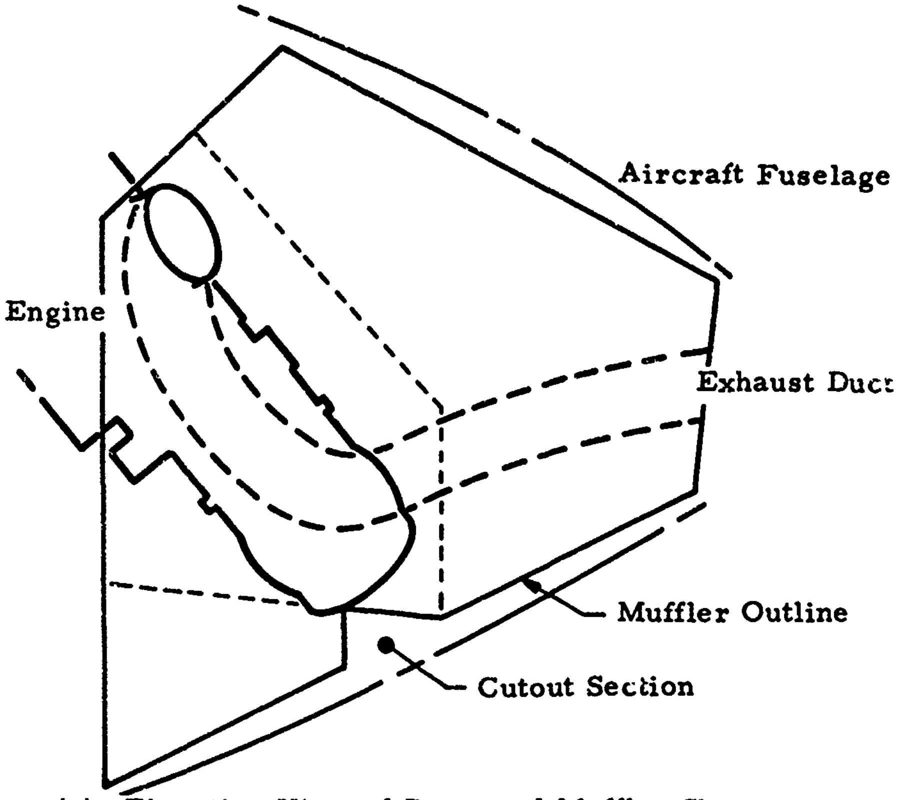


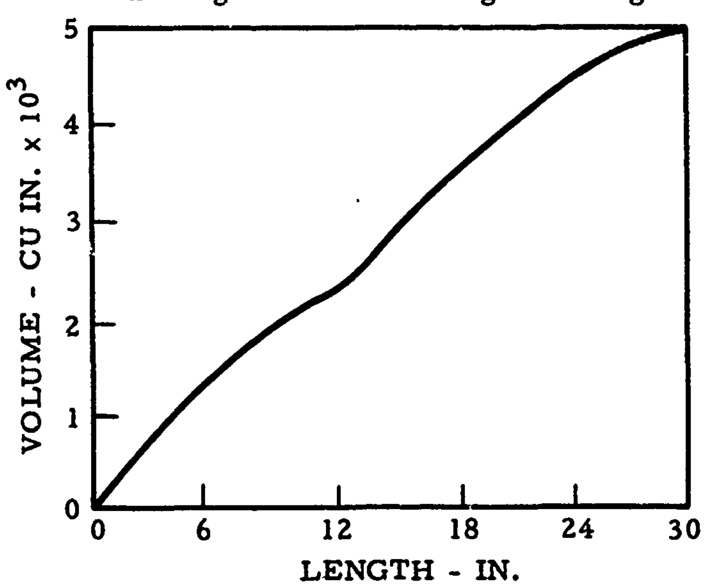
Figure 14. Conceptual Diagram of BB&N Muffler Device.

The prototype muffler is shown installed on the test stand in Figure 17. Ground testing of the prototype muffler revealed that the maximum noise level was between 500 and 700 Hz (Figure 18). This peak noise level may have been due to the muffler shape effect (round muffler flattened into elliptical shape of same cross-sectional area) or an inherent problem with the muffler type. To further suppress this noise range, a tuned single-chamber resonator was designed for attachment in series with the primary muffler. The resonant frequency selected was 600 Hz. Results of acoustic testing of the basic muffler with resonator are shown in Figure 19. The sound power level peaks at 375, 550, and 1000 Hz were dropped appreciably, but not below the noise level objective set for the propulsion system. The schedule precluded further muffler development or testing.

The flight muffler system for the T63-A-5A engine comprises two primary mufflers (one from each exhaust) and a resonator that combines the exhaust from the two mufflers into a single exhaust exit. Each muffler is 36 inches long and has an average cross section of 128 square inches. A baffle with two venturi tubes is installed midway in the muffler to provide two equal-volume chambers. The mufflers have a side inlet, matching the engine exhaust outlet flange, and a circular outlet at the aft end that mates with the resonator. The resonator combines the



(a) Elevation View of Proposed Muffler Shape Showing Aircraft Fuselage and Engine



(b) Volume of Muffler Versus Length of Muffler

Figure 15. Configuration of BB&N Muffler.

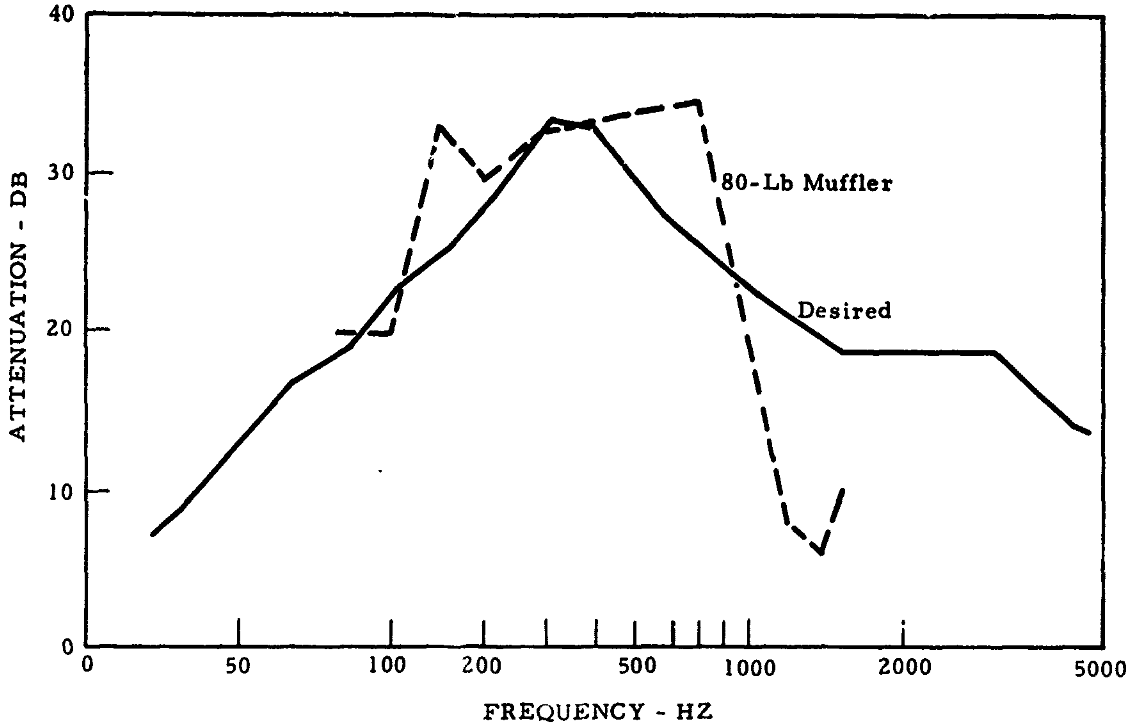


Figure 16. Attenuation for BB&N Muffler.

two muffler exhausts into a single expansion-type exhaust stack that is enclosed by a resonating chamber. The exhaust stack is perforated in the area of the resonating chamber.

The mufflers are constructed of seam-welded 0.020-inch stainless steel, and the resonator is constructed of 0.016-inch stainless. The mufflers are wrapped with 0.5-inch high-temperature insulation and covered with 0.003-inch rigidized corrosion-resistant stainless steel. The resonator is wrapped with an asbestos blanket. The two mufflers are attached together at the front and rear. The resonator is attached to both mufflers by a three-point mounting system. A slip joint and a clamp connect the muffler outlet to the resonator inlet.

The complete assembly, when installed in the aircraft, is supported by the airframe at the rear of the muffler, while the front is attached to each engine exhaust outlet. The single airframe support provides vertical and lateral restraint only. Axial freedom is provided for thermal expansion. The static loads imposed on the engine exhaust collector are below the limits of the engine specification. Engine back-pressure due

Figure 17. Prototype Engine Exhaust Muffler Installed on Test Stand With Tail Pipe Extension.

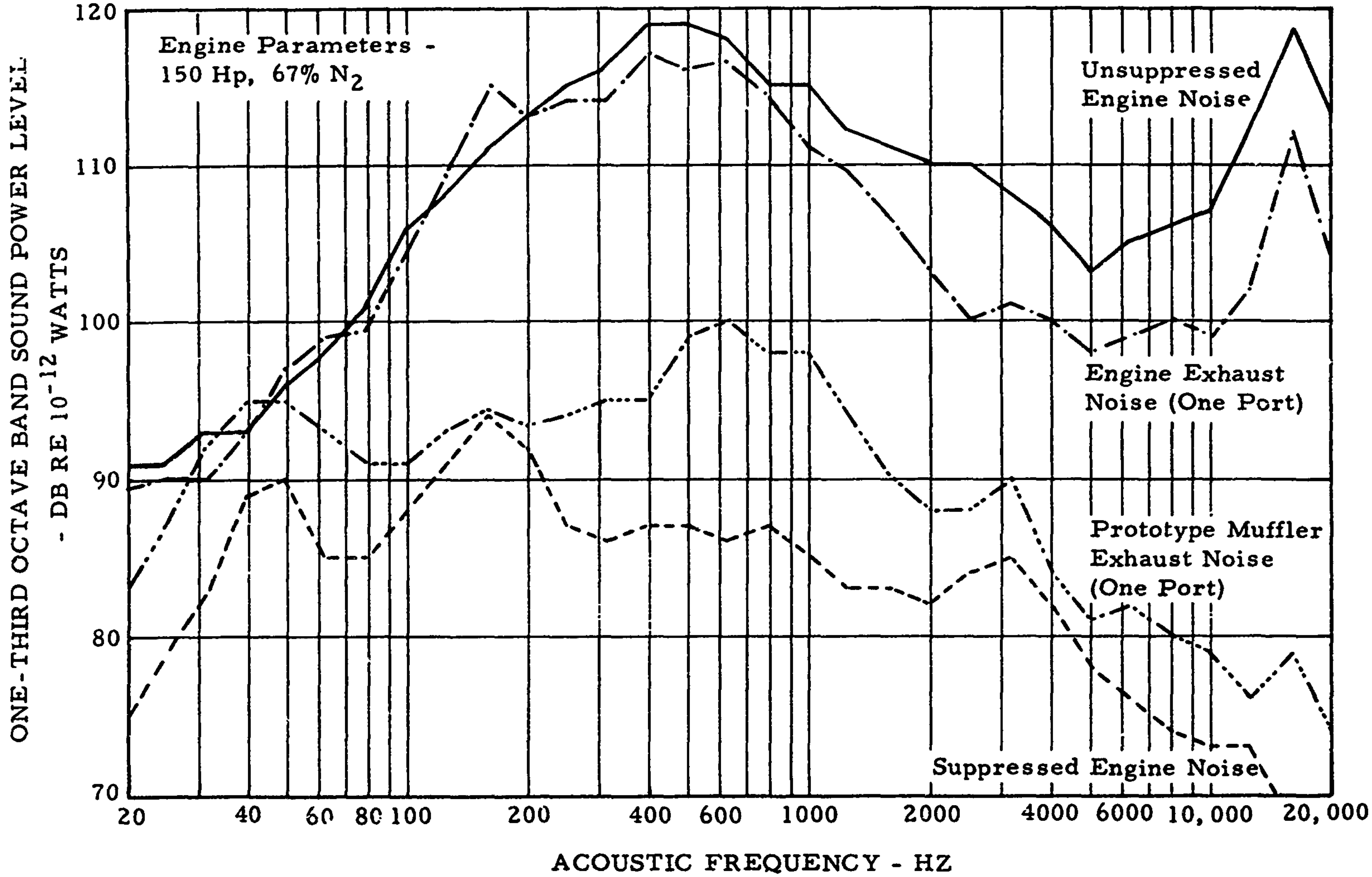


Figure 18. Standard T63-A-5A Engine Exhaust Noise With and Without Prototype HTC Muffler.

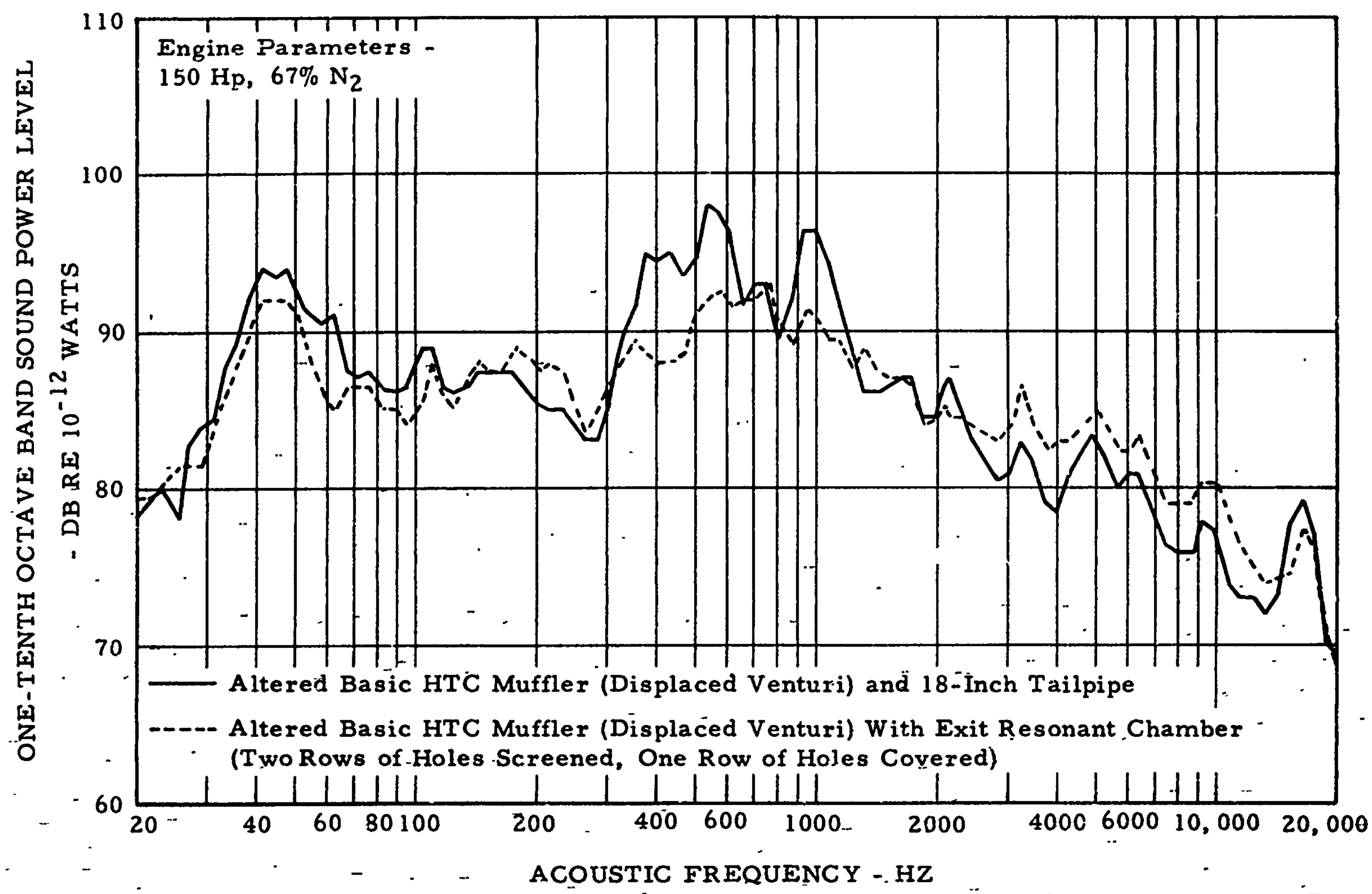


Figure 19. Special T63-A-5A Engine Noise With HTC Muffler and With Resonator Attached.

to the mufflers varies from 15 inches H_2O at 150 hp to 28 inches at 250 hp. This is within the limits specified by the engine manufacturer. The flight muffler installation is shown in Figure 20. Its total installed weight is approximately 80 pounds.

Engine Air Inlet

Requirements for attenuation of engine inlet noise were established on the engine test stand. The inlet noise suppressor is shown in Figure 7. The inlet was constructed of 0.75-inch marine plywood lined with 1-inch-thick Scott foam (90 pores per inch and firmness 3). The attenuation obtained with this suppressor is shown in Figure 9. The "overkill" was appreciable above 3000 Hz. Thus, only certain portions of the air inlet fairing and plenum chamber of the test vehicle had to be lined with sound-absorbent Scott and polyurethane foam for adequate suppression of inlet noise. The forward portion of the fairing was also completely enclosed, to draw air into the plenum chamber from a vertical rather than a horizontal direction.

Engine Compartment and Doors

Engine compartment noise is made up of engine casing noise and exhaust noise flanking the muffler. This noise had to be attenuated to an acceptable level by the engine-compartment walls. Casing noise sources with the special engine are identified in the sound-pressure-level spectrum shown in Figure 21. This spectrum revealed that the engine casing noise had to be reduced approximately 15 db between 100 and 10,000 Hz. Flight muffler flanking noise was not measured on the aircraft; therefore, the exhaust noise from both ports (Figure 8), reduced by the transmission loss of the muffler, was used to establish its attenuation requirement. Here again, it was determined that a 15-db reduction would be required between 100 and 10,000 Hz.

The engine compartment (fire zone) was lined with a 2-inch-thick layer of silicone-bound fiberglass and covered with a layer of 0.003-inch rigidized corrosion-resistant steel sheet. All joints were sealed with aluminum-foil tape. The cargo compartment side of the firewall was similarly modified. All openings, such as those for the landing gear struts, were filled with closed-cell Scott foam and covered with a fire-resistant material.

Figure 20. Muffler Installation.

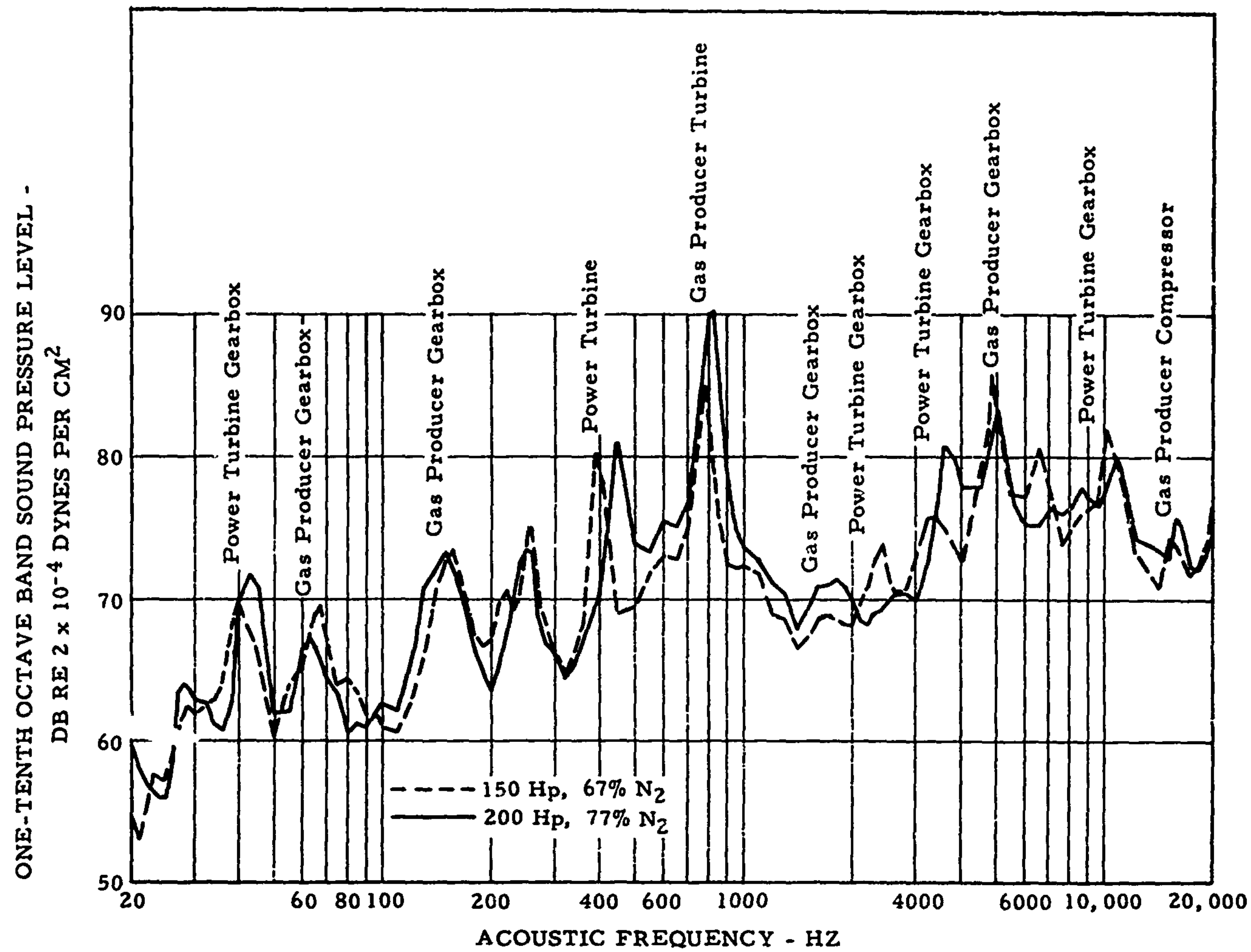


Figure 21. Special T63-A-5A Engine Casing Noise, Microphone Position 10 Feet Left and 80 Degrees From Engine (Forward) Centerline.

New engine doors were designed to accommodate the muffler installation and provide the necessary attenuation. A tight seal was needed to prevent noise leakage. The doors are of double-wall construction consisting of a 0.020-inch aluminum alloy outer skin, a 2-inch layer of loosely compressed fiberglass, and an inner wall. The forward 60 percent of the doors is lined with 0.003-inch rigidized corrosion-resistant steel. To prevent noise from leaking through the annular engine cooling air exit passage, between the exhaust resonator and the inner wall of the doors, a sound trap was created by lining the aft 40 percent of the doors with a layer of window screen covered with a sheet of 24 percent open, perforated aluminum. Figure 20 shows the engine doors. This design concept was successful in obtaining the required db reductions and in preventing noise leakage through the cooling air exit area.

Fully Configured Quiet Helicopter

Figure 22 is a three-view and inboard profile drawing of the Quiet Helicopter, and Figure 23 is a photograph of the "Quiet One" in flight.

Weight and Balance

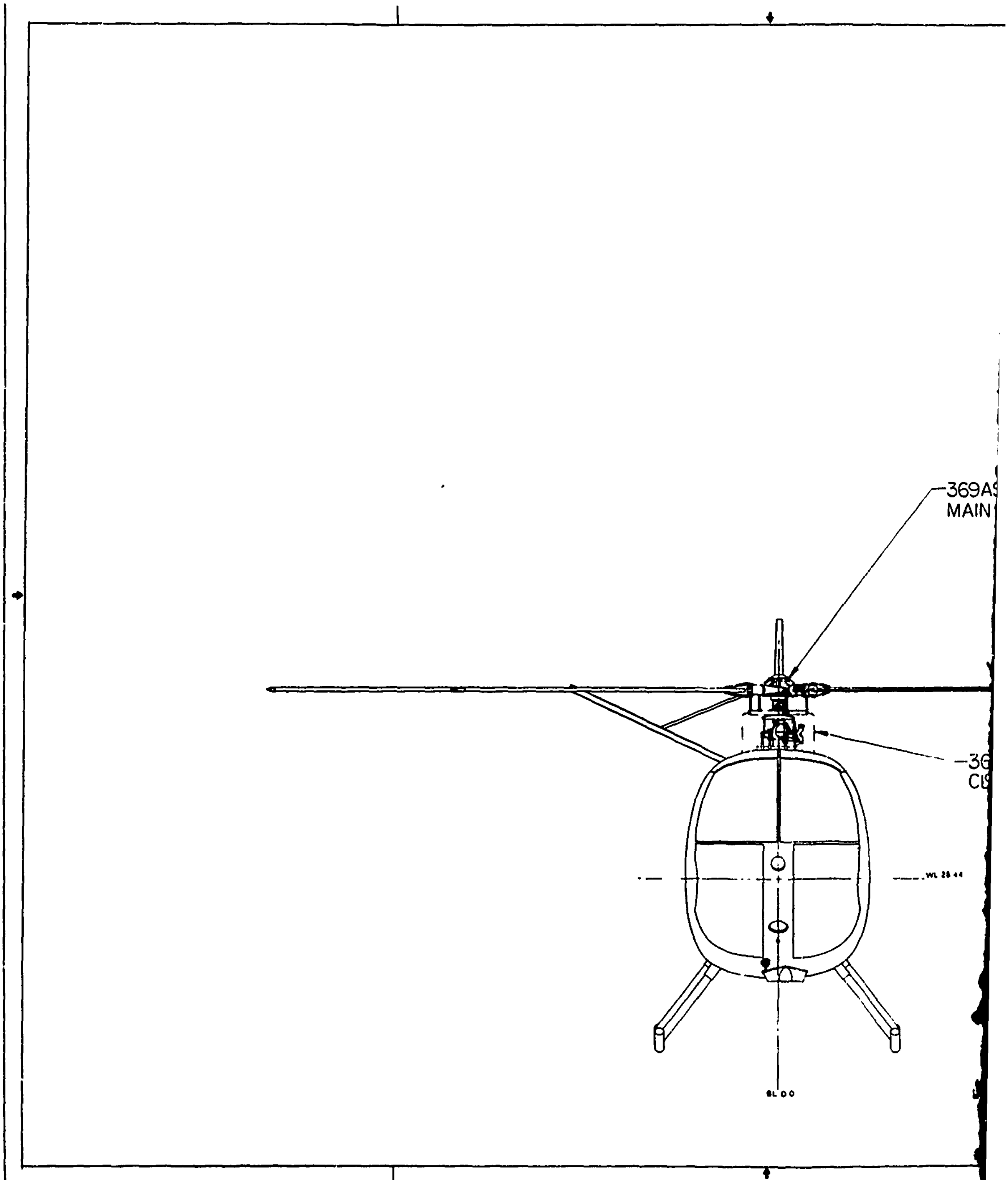
The basic weight of the helicopter was increased 192 pounds with the incorporation of the quieting features. This represents a 15 percent loss in useful load for the standard OH-6A, which has a maximum Army-approved gross weight of 2400 pounds. However, the added rotor capability at 100 percent N_2 will permit increasing the gross weight to 3150 pounds -- a payload increase of more than 85 percent.

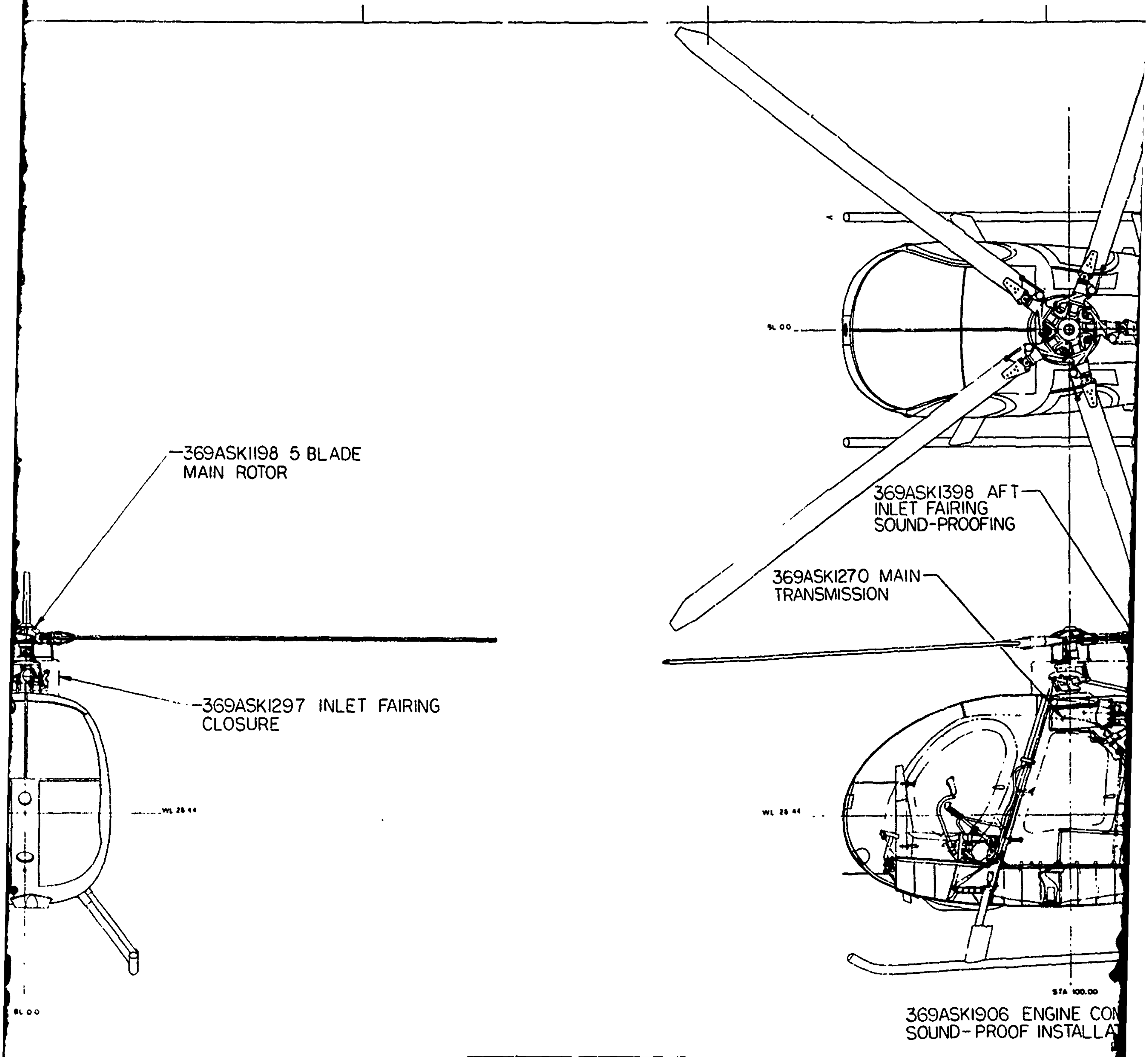
The permissible longitudinal center-of-gravity range for the Quiet Helicopter is from 4 inches forward to 7 inches aft of the main-rotor centerline (stations 97 to 107). Since most of the weight was added aft of the main-rotor centerline, the center of gravity of the aircraft moved from station 109 to station 114.9, making it necessary to carry forward ballast when operating at 1600 pounds to remain within the aft limit. Ballast is not required, however, when operating the aircraft at heavier gross weights with the usual avionics equipment installed in the forward areas.

FLIGHT STRAIN SURVEY

An instrumented flight test program was conducted to obtain dynamic loads, rotor rpm decay rates, and rate of descent for establishing a safe flight envelope. The purpose was to modify parts as required to minimize or eliminate those conditions that could produce loads beyond the endurance limits. To achieve this purpose, data were recorded on the following items:

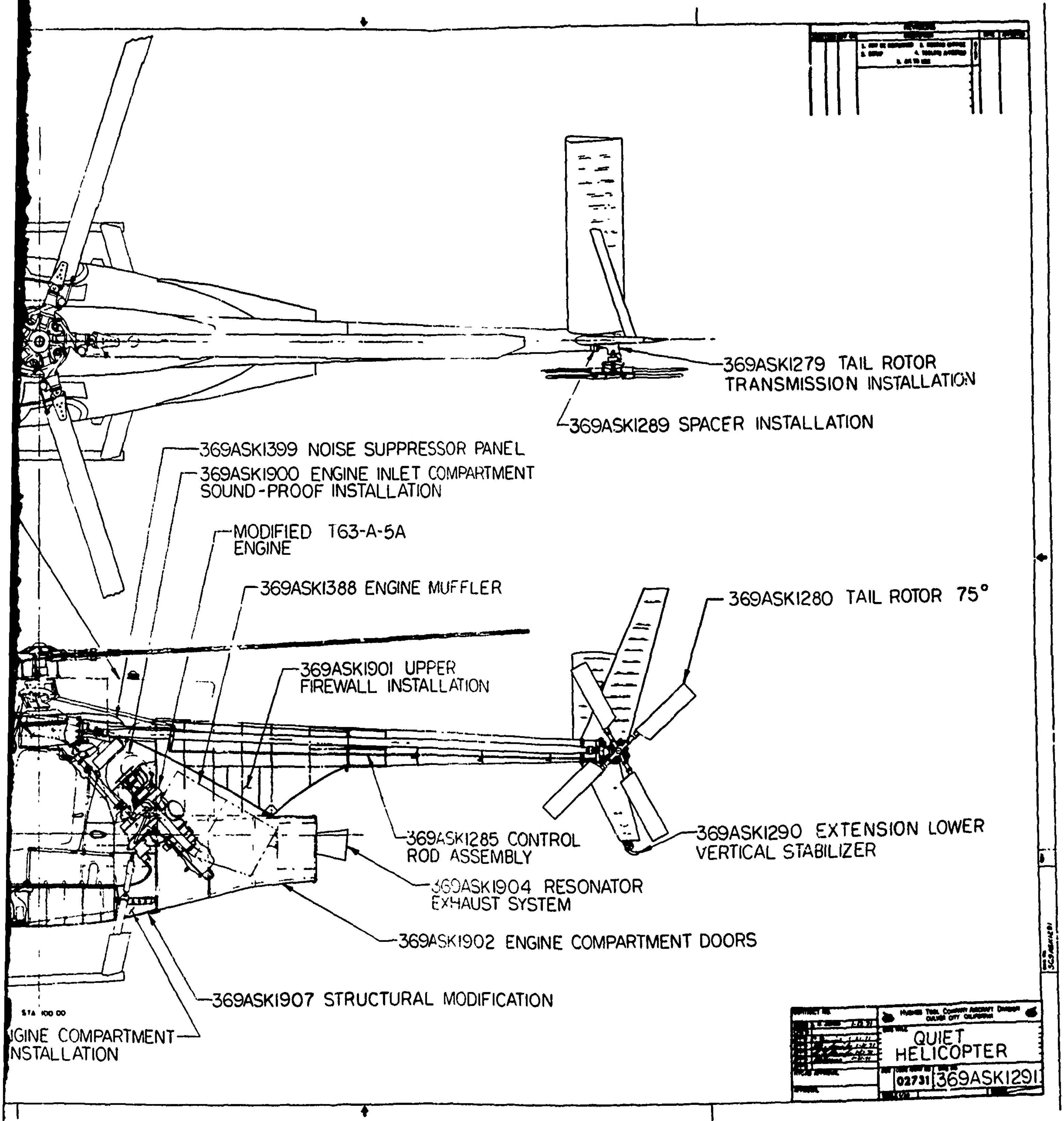
Airspeed
Engine torque
Altitude
Vertical acceleration
Yaw angle
Yaw rate
Rotor rpm
Longitudinal cyclic position
Lateral cyclic position
Collective position
Pedal position
Main rotor pitch housing flapwise bending
Main rotor blade flapwise bending, station 23.65
Main rotor blade chordwise bending, station 29.80
Main rotor blade torsion, station 29.80
Main rotor blade flapwise bending, station 31.55
Main rotor blade flapwise bending, station 47.30
Main rotor blade flapwise bending, station 78.80
Main rotor blade chordwise bending, station 78.80
Main rotor blade flapwise bending, station 110.35
Main rotor blade flapwise bending, station 147.85
Main rotor drive shaft torque
Main rotor pitch link load (2)
Lead-lag position (3)
Tail rotor blade flapwise bending, inboard (2)
Tail rotor blade chordwise bending, inboard (2)
Tail rotor hub flapwise bending (1)
Tail rotor hub chordwise bending (1)
Tail rotor pitch link load
Tail rotor transmission output shaft bending, inplane
Tail rotor transmission output shaft bending, 90 deg
Tail rotor drive shaft torque
Main rotor static mast upper longitudinal bending
Main rotor static mast upper lateral bending
Main rotor static mast base longitudinal bending
Main rotor static mast base lateral bending
Tail boom vertical forward bending
Tail boom horizontal forward bending
Tail boom vertical aft bending
Tail boom horizontal aft bending
Tail boom aft torque
Horizontal stabilizer flapwise bending, inboard


-369A
MAIN
-36
CL
WL 25.44
BL 0.0



369ASK1198 5 BLADE MAIN ROTOR
369ASK1297 INLET FAIRING CLOSURE
BL 00
369ASK1398 AFT INLET FAIRING SOUND-PROOFING
369ASK1270 MAIN TRANSMISSION
STA 100.00
369ASK1906 ENGINE CO
SOUND-PROOF INSTALLA

369ASK1291


369ASK1279 TAIL ROTOR
TRANSMISSION INSTALLATION
369ASK1289 SPACER INSTALLATION
369ASK1399 NOISE SUPPRESSOR PANEL
369ASK1900 ENGINE INLET COMPARTMENT
SOUND-PROOF INSTALLATION
MODIFIED T63-A-5A
ENGINE
369ASK1388 ENGINE MUFFLER
369ASK1280 TAIL ROTOR 75°
369ASK1901 UPPER
FIREWALL INSTALLATION
369ASK1285 CONTROL
ROD ASSEMBLY
369ASK1290 EXTENSION LOWER
VERTICAL STABILIZER
369ASK1904 RESONATOR
EXHAUST SYSTEM
369ASK1902 ENGINE COMPARTMENT DOORS
369ASK1907 STRUCTURAL MODIFICATION
GINE COMPARTMENT
NSTALLATION
QUIET
HELICOPTER
02731
369ASK1291

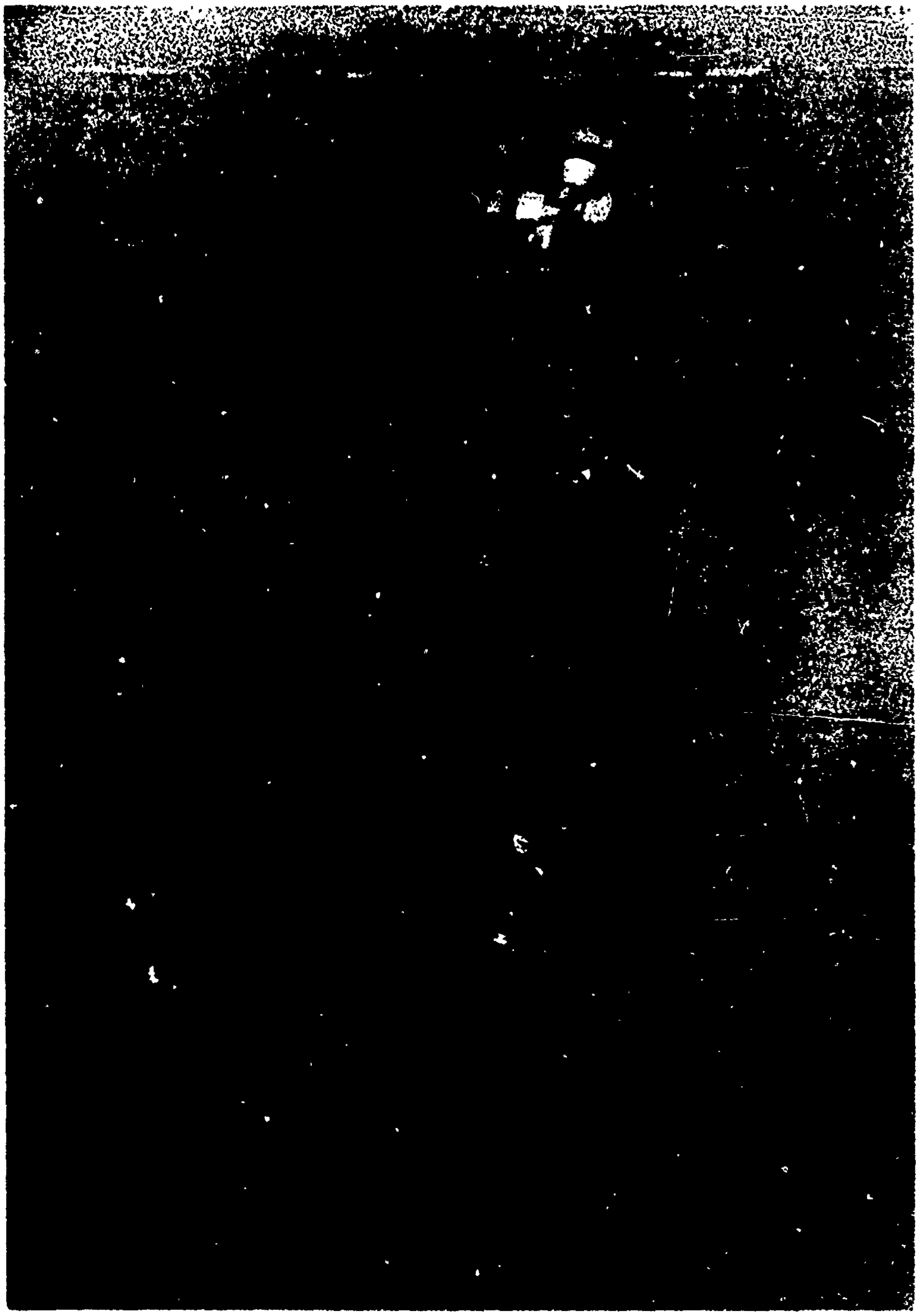


Figure 23. The "Quiet One".

Horizontal stabilizer flapwise bending, outboard
Horizontal stabilizer chordwise bending
Upper vertical stabilizer flapwise bending, inboard
Upper vertical stabilizer flapwise bending, outboard
Upper vertical stabilizer chordwise bending
Lower vertical stabilizer flapwise bending

The envelope was expanded systematically for gross weights ranging from 1600 to 2400 pounds at N_2 speeds from 67 to 103 percent. The forward-flight envelope was explored to 145 knots at 2400 pounds and 100 percent N_2.

During the flight strain survey, excessive tail rotor loads were encountered during some flight conditions. This was corrected by improving the chordwise mass balance, increasing weight and contour stiffness at the blade tips, and reducing the stiffness of the tail-rotor fork between the inboard and outboard sets of blades.

The general handling characteristics of the Quiet Helicopter, at 100% N_2, are as good as or better than those of the OH-6A. The aircraft is more responsive in cyclic control, yet main rotor damping is better than that of the standard OH-6A. Tail-rotor control is satisfactory for all conditions, including lightweight hover at 67 percent N_2. Except for a light 1-per-rev lateral vibration, the ship is very smooth at airspeeds up to 145 knots. A momentary and unsustained 5-per-rev vibration is experienced during landing flare. This is similar to the 4-per-rev in the standard aircraft.

Analysis of the loads data for the final configuration resulted in the following operating limitations for the acoustics measurement portion of the program:

1. Gross weight and center of gravity

Maximum gross weight	2400 pounds
Longitudinal cg limits	Stations 97 to 107
Lateral cg limits	±3 inches

2. Minimum N_2 requirements

2400-pound gross weight	78 percent N_2
2000-pound gross weight	70 percent N_2
1600-pound gross weight	67 percent N_2

3. Airspeed

At 100 percent N_2	130-KIAS V_{ne}
Below 100 percent N_2	70-KIAS V_{ne}

4. Rotor speed

Maximum power-off	490 rpm
Maximum power-on	470 rpm (100 percent)
Minimum power-off	400 rpm
Minimum power-on	315 rpm (67 percent)

5. Flight limitations at reduced rpm

Maximum bank angle, 30 deg or 1.25 g.

No flights in winds greater than 10 knots.

No sharp maneuvers, especially pedal kicks or reversals.

Do not exceed 2-inch left pedal displacement on the ground.

Do not exceed a yaw rate of 10 degrees per second (15 degrees sideslip) in forward flight or 30 degrees per second in hover.

Minimize use of left turns in hover and forward flight.

Conduct operations other than level flight and hover for acoustical data at 100 percent N_2.

ENGINE COOLING TESTS

Tests were conducted to ensure that the engine was being adequately cooled with the muffler system installed. Thermocouples were used to record temperatures at critical locations on and in the vicinity of the engine.

During hover flight at 1700 pounds and 100 percent N_2, the maximum allowable temperature (450°F) was recorded at a location 3 inches above the engine thermocouple harness. Upon reducing the N_2 speed to 67 percent, the temperature rose rapidly to 486°F and reached a peak of 498°F by the time the run was aborted. The temperature at all other locations remained within the allowable limits.

To solve this problem, the standard OH-6A cooling blower was replaced by a higher-capacity unit and the upper engine compartment cooling duct was relocated to provide additional cooling air to the "hot" area. All engine-compartment temperatures then remained within limits during hover flight at 100 to 67 percent N_2 (1700-pound gross weight) and 100 to 78 percent N_2 (2400-pound gross weight).

ACOUSTIC RESULTS

Limited acoustics measurements of the fully configured Quiet Helicopter were conducted. The instrumentation used is shown in the appendix, and the microphone layout is shown in Figure 24. Measurements were recorded during a 6-foot hover at azimuth headings of 0, 45, and 180 degrees with the microphones located 200 feet from the aircraft. Flyover measurements were made at 100-foot altitude at 70 knots over the runway. Gross weights of 1600 and 2400 pounds (nominal) were flown at N_2 speeds of 67 and 78 percent, respectively. Some measurements were also made at 100 percent N_2 amd 120 knots.

The hover noise spectra in Figures 25 and 26 compare the Phase II Quiet Helicopter at 1600 pounds and 67 percent N_2 with the standard OH-6A at 1450 pounds and 100 percent N_2. Figure 25 shows a 20-db decrease in the first-harmonic rotational noise of the main rotor, from 79 db at 31.5 Hz to 59 db at 27 Hz. The first-harmonic rotational noise of the tail rotor was substantially decreased -- from 84 db at 100 Hz to 54 db at 44 Hz (30 db). The exhaust-pipe resonance at 125 Hz and exhaust noise between 300 and 100 Hz have also been reduced.

Engine gearing noise in the range between 200 and 6000 Hz is actually higher in the front view (Figure 25) than in the rear view (Figure 26). This high-frequency noise may be leaking from the engine compartment through the engine-mounting system or the engine-to-transmission drive shaft.

Figure 27 presents the hover results. A 17-db reduction in OASPL was achieved at 1600 pounds. The reduction in hover OASPL decreased to 14 db at a gross weight of 2500 pounds. Figure 28 shows the results of the flyover acoustic measurements. Appreciable reductions are seen across the entire spectrum with a 15-db reduction in OASPL.

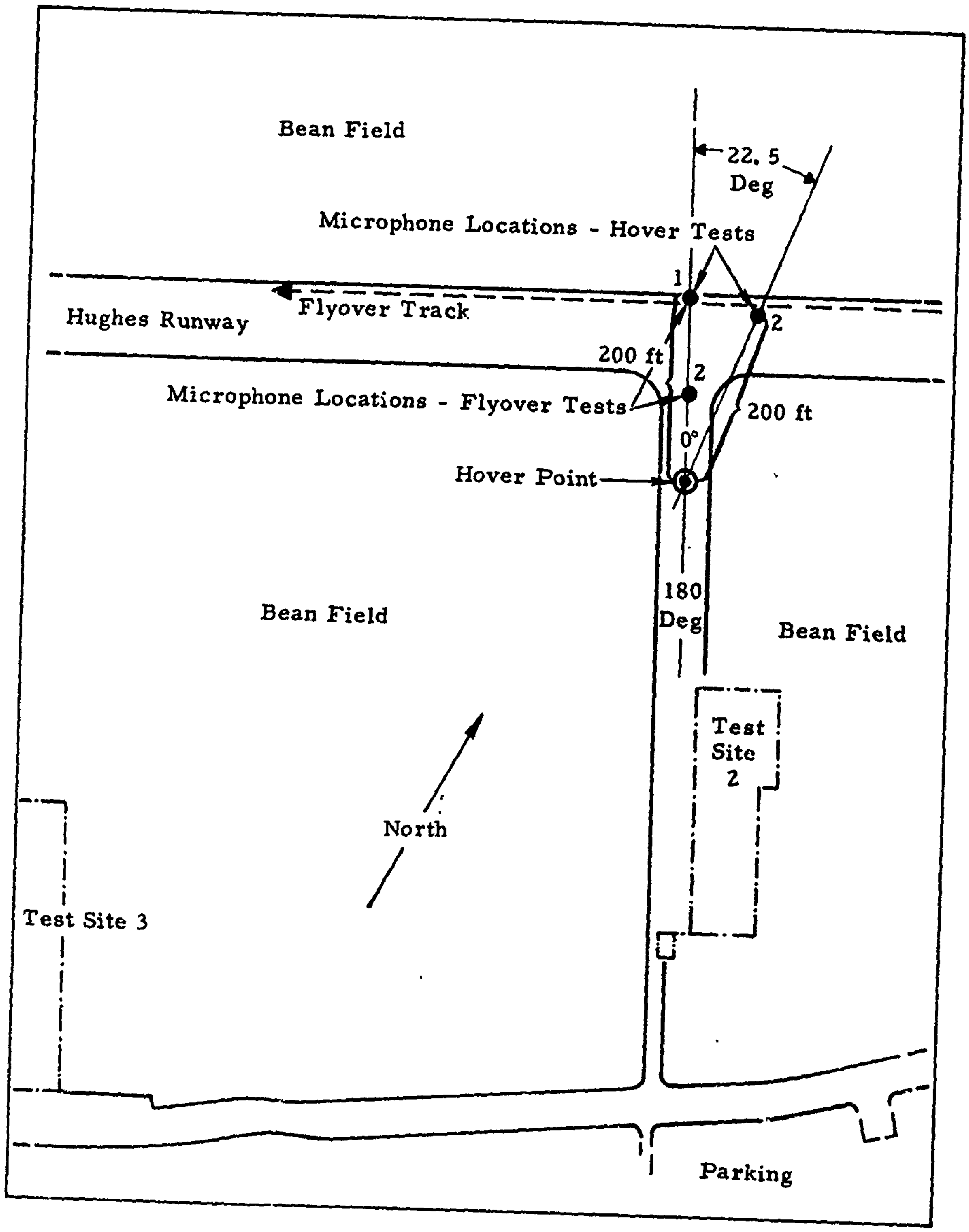


Figure 24. Microphone Locations.

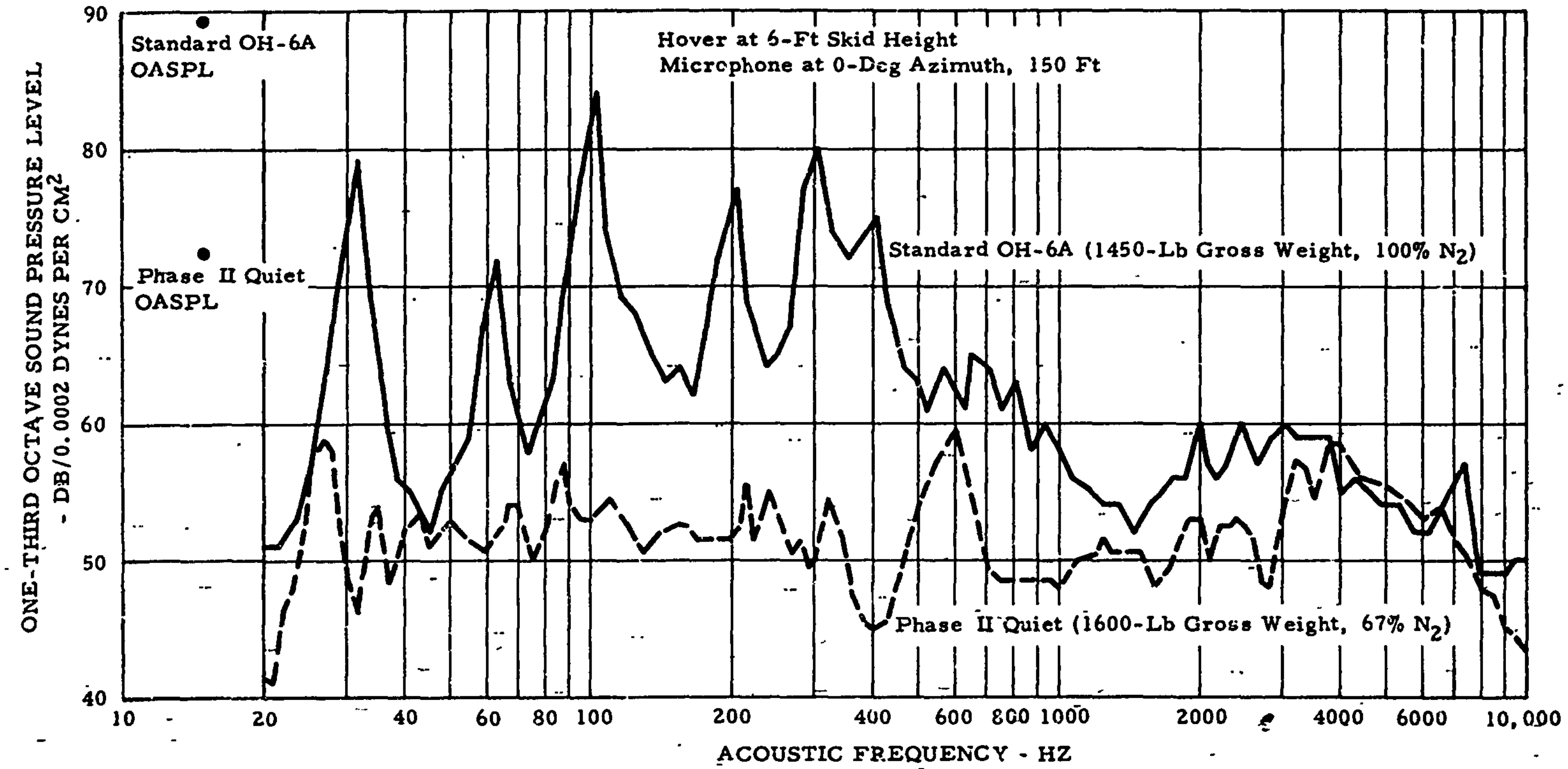


Figure 25. Sound Pressure Level Spectrum Comparison in Hover - 0-Degree Heading Relative to Recording Microphone - Standard OH-6A and Phase II Quiet Helicopter.

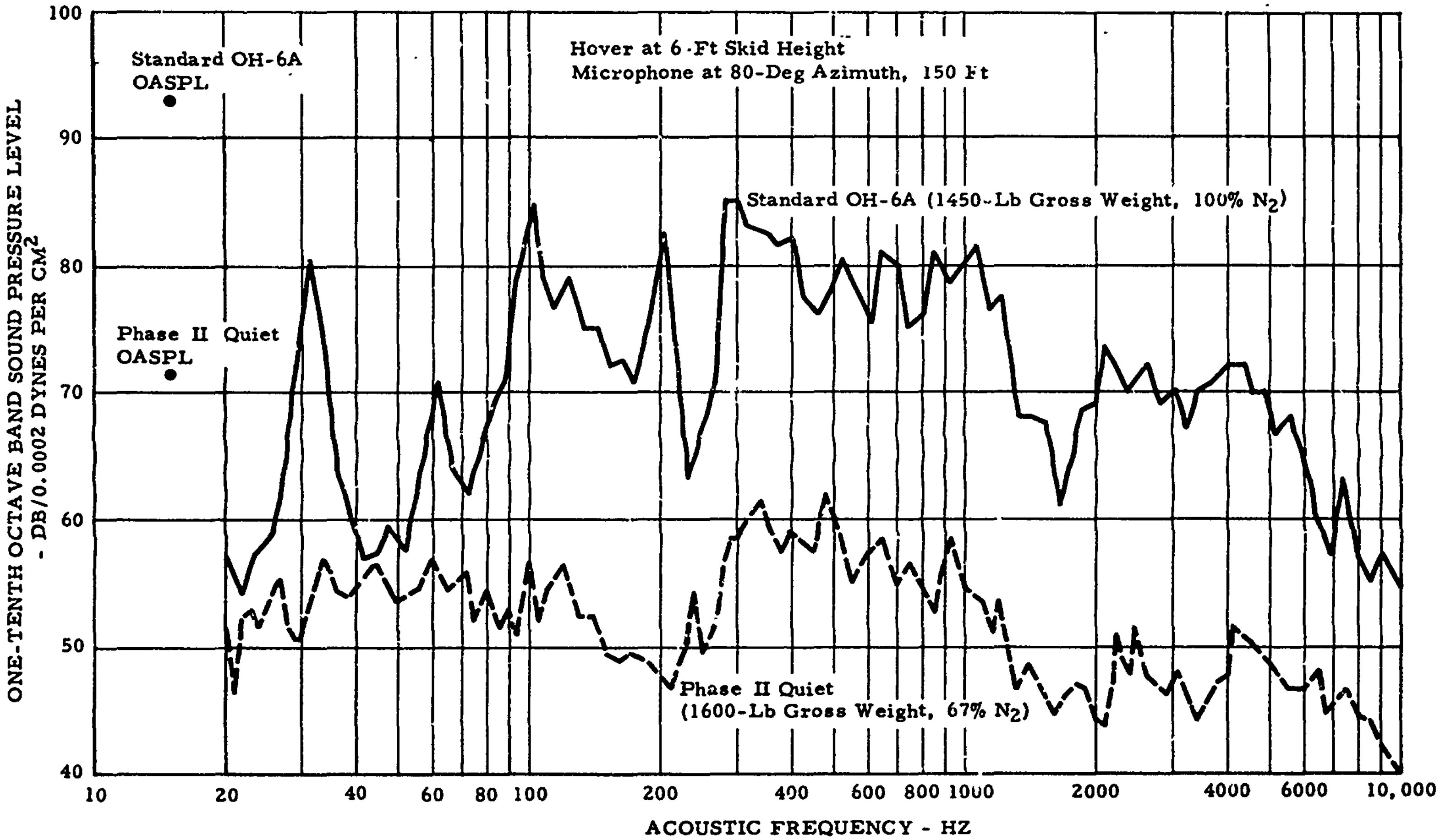


Figure 26. Sound Pressure Level Spectrum Comparison in Hover - 180-Degree Heading Relative to Recording Microphone - Standard OH-6A and Phase II Quiet Helicopter.

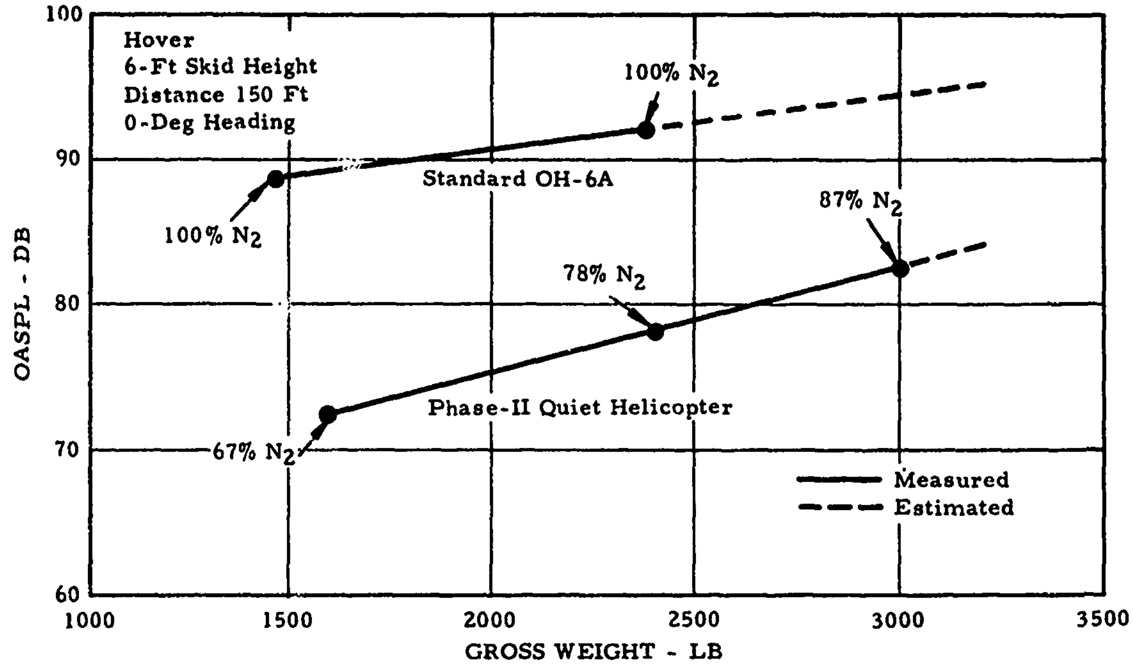


Figure 27. Noise Level Comparison in Hover.

Concurrently with instrumented noise measurements, a series of stop-watch measurements were made at low-ambient-noise conditions to determine the maximum distance at which several observers could aurally detect the standard OH-6A and the Phase II Quiet Helicopter during 70-knot approaches at 100-foot altitude. Table V presents the results of these tests. The average detection range of the standard OH-6A was 6 to 7 times greater than that of the Quiet Helicopter, even when operating both aircraft at 2400 pounds, 100 percent N_2, and 120 knots.

An attempt to correlate the instrumented results with the aural (stopwatch) data by calculating aural detection ranges using the methods established by J. B. Ollerhead[10] was unsuccessful. The many environmental variables in the test area could drastically alter the ground attenuation. The comparison between the calculated and stopwatch detection ranges for the Quiet Helicopter in Figure 29 shows only that the gross effects of weight and N_2 speed may be predicted.

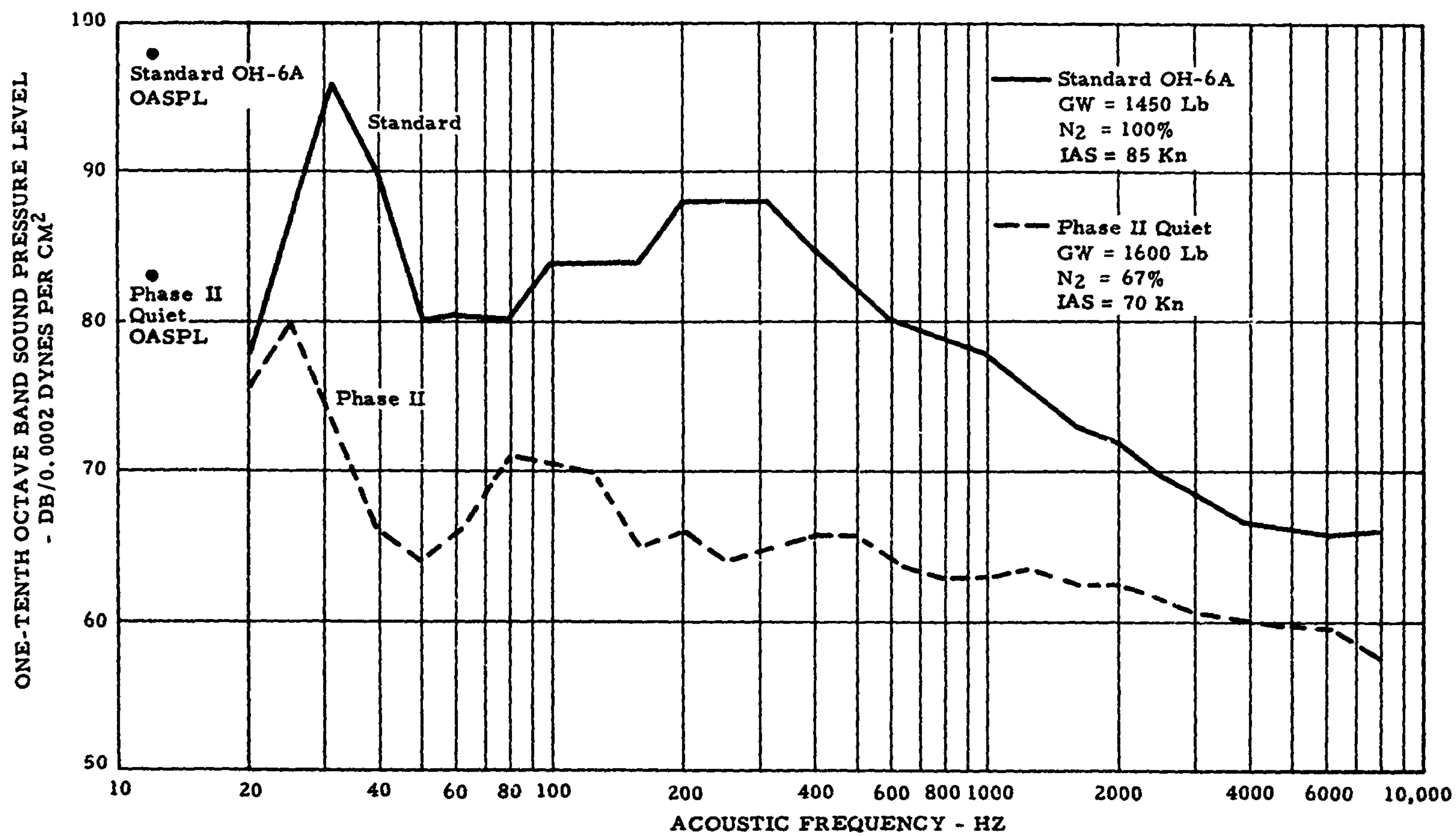


Figure 28. Flyby Overhead Noise Spectrum Comparison at 100-Foot Altitude - Standard OH-6A and Phase II Quiet Helicopter

TABLE V. STOPWATCH TEST RESULTS - PHASE II QUIET HELICOPTER PROGRAM

Helicopter	Quiet	OH-6A	Quiet	OH-6A
Conditions				
Gross weight, lb	1600	2400	2400	2400
N_2, pct	67	100	100	100
Altitude, ft	100	100	100	100
V_0, kn	70	70	120	120
Ambient OASPL, db	58	58	65	65
Observer time increment, sec				
Lt. Col. G. A. Briscoe	9.7	55.3	6.6	39.5
H. W. Ferris	5.9	-	6.0	40.6
N. B. Hirsh	9.9	57.7	6.9	40.0
Average detection distance, yd	335	2226	439	2703
Ratio, OH-6A/Quiet Helicopter	2226/335 = 6.65		2703/439 = 6.16	

Figure 30 shows an aural detection comparison with the standard OH-6A as a function of gross weight. Although the aural detection distance increases with increases in gross weight and rotor rpm, the rate of increase is small. For example, the detection distance at 67% N_2 and 1600 pounds is 300 feet; at 78% N_2 and 2400 pounds, it is 400 feet.

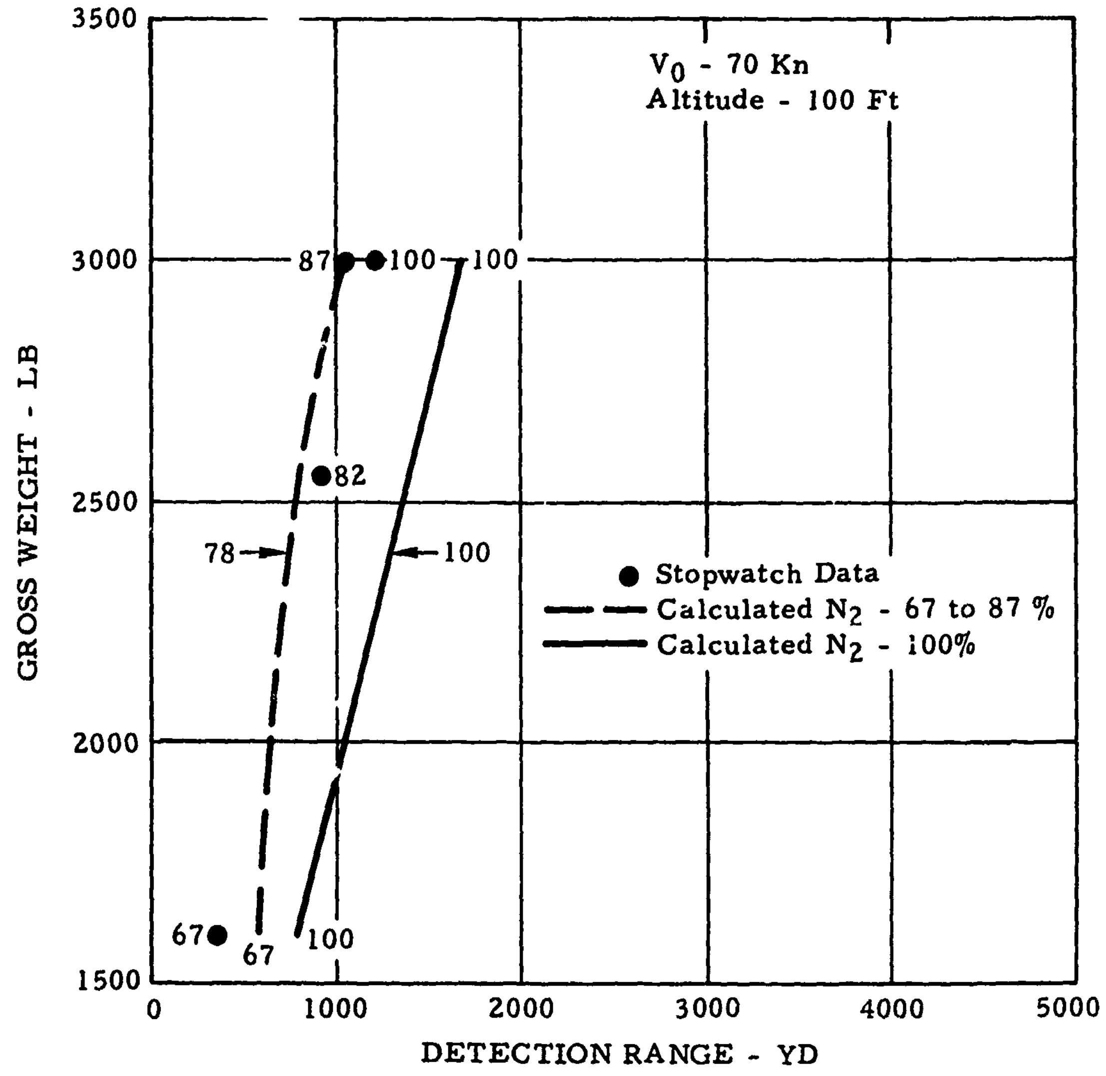


Figure 29. Calculated and Stopwatch Aural Detection Range.

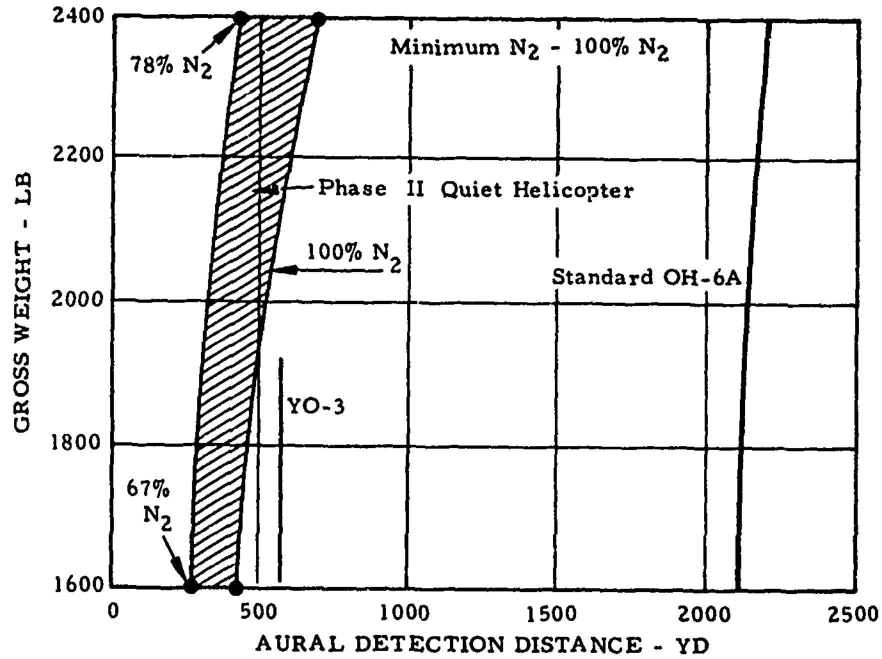


Figure 30. Aural Detection Range of Approaches.

CONCLUSIONS

A modified, quiet OH-6A helicopter was designed, fabricated, and tested. Its external noise level was reduced 17 to 20 db in hover and 14 to 16 db in level flight. Aural detection distances were reduced by a factor of more than 6 to 1.

LITERATURE CITED

1. Henderson, Herbert R., and Hilton, David A., DESCRIPTION OF THE NOISE MEASUREMENT PROGRAM ON A STANDARD AND THE MODIFIED PHASE II HUGHES OH-6A HELICOPTER LWP - 963, National Aeronautics and Space Administration May 26, 1971.

2. PROGRAM TO REDUCE THE NOISE SIGNATURE OF THE OH-6A HELICOPTER, HTC-AD Report 70-26, Hughes Tool Company - Aircraft Division, Culver City, California.

3. Schlegel, Ronald, King, Robert, and Mull, Harold, HELICOPTER ROTOR NOISE GENERATION AND PROPAGATION, USAAVLABS Technical Report 66-4, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia October 1966, AD 645884.

4. Spivey, R.F., BLADE TIP AERODYNAMICS - PROFILE AND PLANFORM EFFECTS, presented at 24th Annual National Forum of the American Helicopter Society, Bell Helicopter Company, Fort Worth, Texas, May 1968.

5. Cary, Beecher B., SOME ACOUSTIC PROBLEMS OF THE AUTOMOTIVE FAN, Journal of the Acoustic Society of America, Volume 10, July 1938.

6. Lowson, M.V., and Ollerhead, J.B., STUDIES OF HELICOPTER ROTOR NOISE, USAAVLABS Technical Report 68-60, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, January 1969, AD 684394.

7. Morse, P.M., The Acoustic Society of America, Volume 11, 205 (1939).

8. Cremer, L., Acoustica 3, 249 (1953).

9. Davis, Don D. Jr., Stokes, George M., Moore, Dewey, and Stevens, George L., Jr., THEORETICAL AND EXPERIMENTAL INVESTIGATION OF MUFFLERS WITH COMMENTS ON ENGINE-EXHAUST MUFFLER DESIGN, NACA Technical Report 1192, LMAL.

10. Ollerhead, J. B., Appendix II of HELICOPTER AURAL DETECTABILITY, Wyle Laboratories, Hampton, Virginia, USAAMRDL Technical Report 71-33, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1971, AD 730788.

APPENDIX

INSTRUMENTATION

The acoustic equipment used for the sound-level measurements and data reduction is listed below and is shown in Figures 31 and 32. The equipment used during the study of amplitude modulation of the helicopter noise is shown schematically in Figure 33.

ACOUSTIC EQUIPMENT

1. Tape Recorder
2. Oscilloscope
3. Oscillator
4. Electronic Counter
5. Sound Level Meter
6. Frequency Analyzer
7. Condenser Microphone
8. Analyzer
9. Cathode Follower
10. Pistonphone Calibrator
11. Sound Level Recorder
12. Oscillograph
13. Amplifier
14. Integrator
15. Accelerometer

Microphone locations are identified in the text for each specific test. Microphone frequency responses are flat to within ±0.5 decibel over the range of 20 to 15,000 Hz. The outputs of both microphones were recorded on the multichannel tape recorder. Both noise measurement channels were calibrated at the test site before and after the acoustic measurements by means of a pistonphone calibrator.

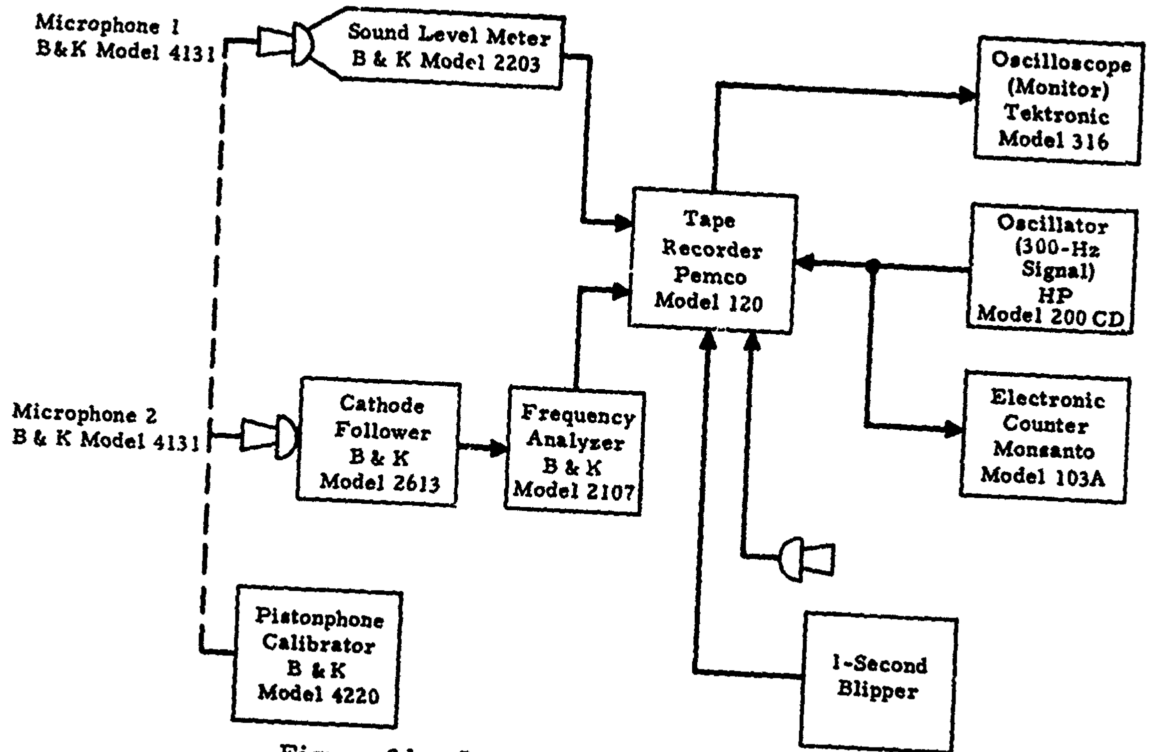


Figure 31. Sound Recording System.

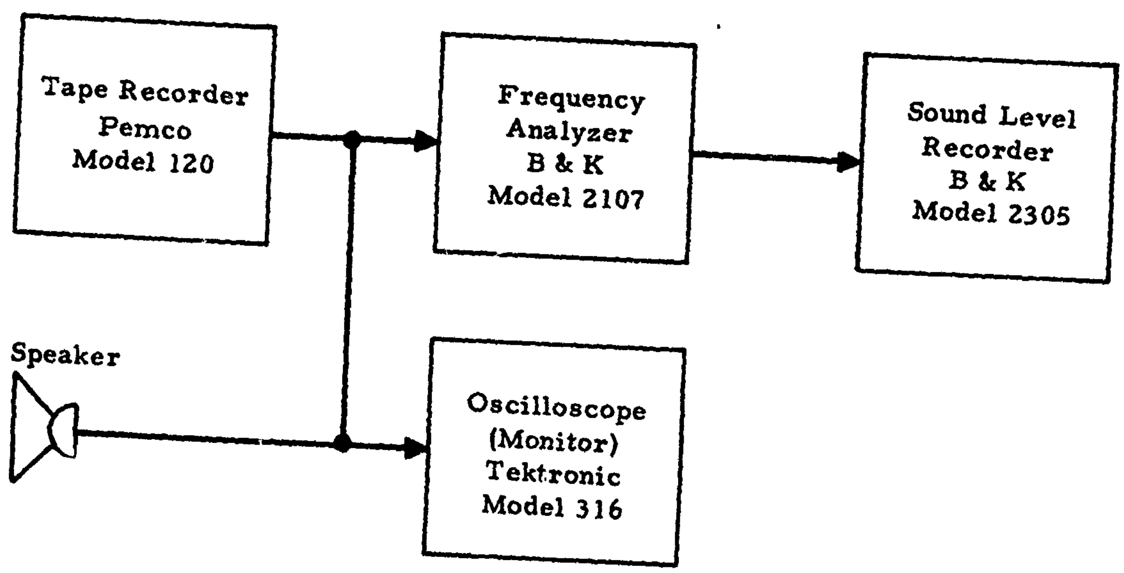


Figure 32. Data Reduction System.

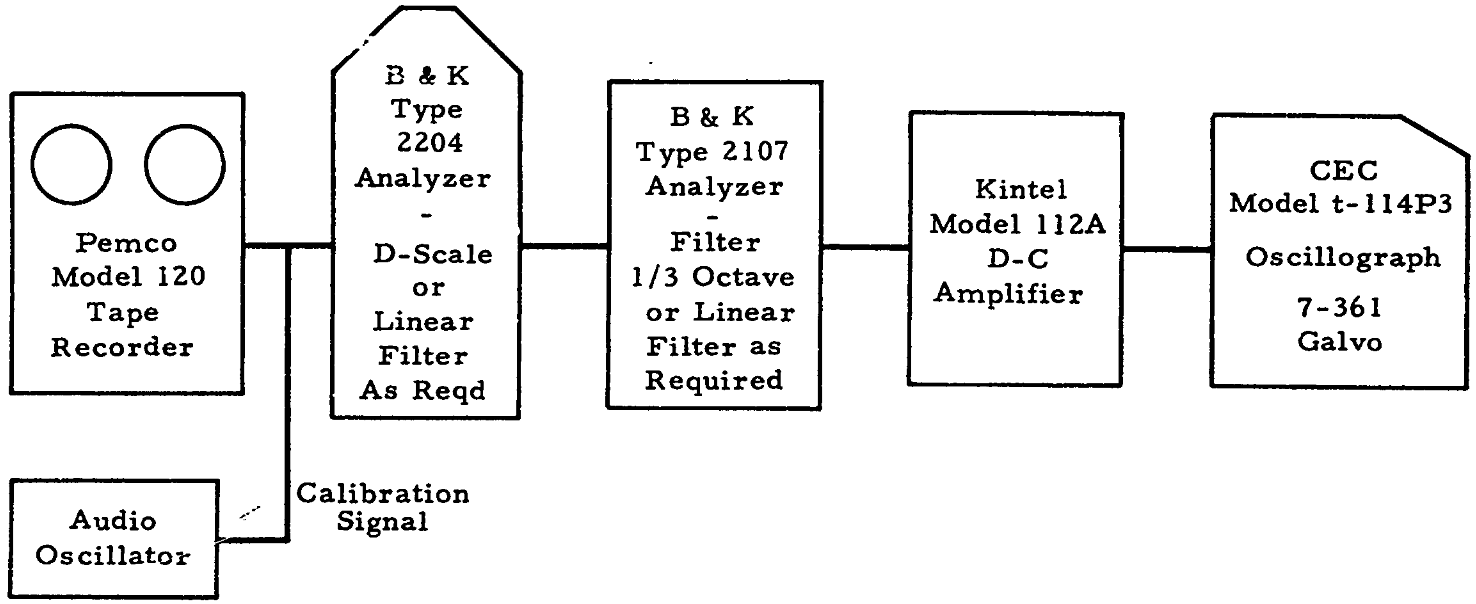


Figure 33. Amplitude Modulation Instrumentation.